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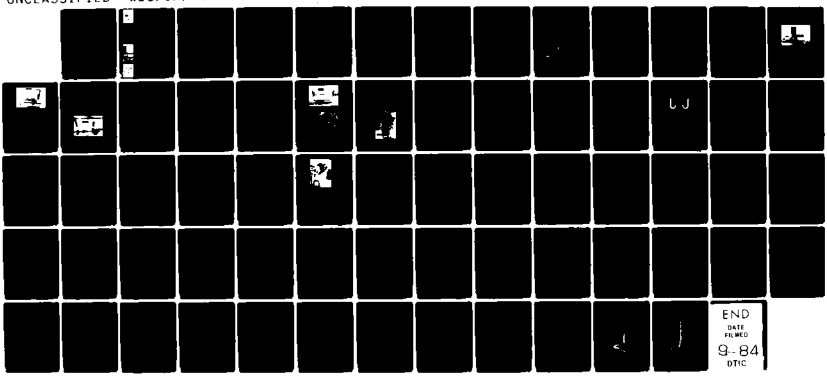

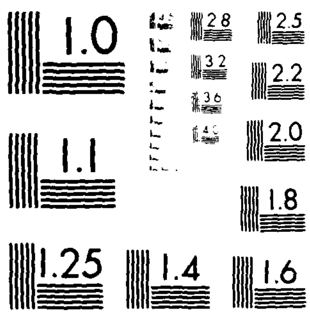

MICROCOPY RESOLUTION TEST CHART

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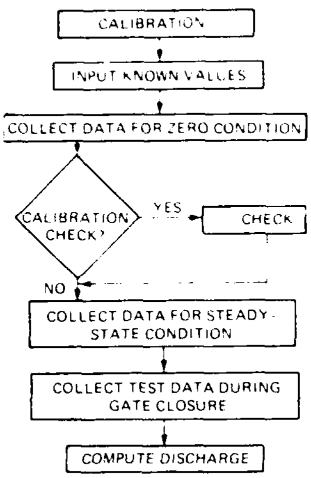

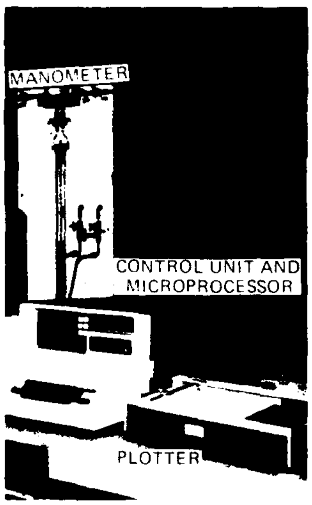

HYDRAULICS LABORATORY

INSTRUCTION REPORT HL-84-1

OPERATION MANUAL: PRESSURE-MOMENTUM METHOD OF DISCHARGE MEASUREMENT

by

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This instruction report describes automated procedures for conducting discharge measurements in a closed conduit with facilities for shutting off the flow at a downstream location. The method described herein is a modification, developed at the U. S. Army Engineer Waterways Experiment Station (WES), of the proven Gibson (pressure-momentum) Method.

The WES apparatus used in performing the tests consists of a Data

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20. ABSTRACT (Continued).

Acquisition and Control System (DACS) which includes all components of the measurement, data recording, and data analysis system. The control unit and microprocessor of the system are programmed to guide the operator through the complete test. This includes calibration, data acquisition, and computations, thereby providing a complete onsite analysis. This manual outlines the step-by-step procedures involved.

PREFACE

This instruction report describes procedures to be used in conducting discharge measurements of closed conduit flow by the pressure-momentum method. This method, a modification of the Gibson Method, was developed by the U. S. Army Engineer Waterways Experiment Station (WES) under the sponsorship of the U. S. Army Engineer District, Omaha.

This manual was prepared under the supervision of Messrs. H. B. Simmons, Chief of the Hydraulics Laboratory, WES; M. B. Boyd, Chief of the Hydraulics Analysis Division; and E. D. Hart, Chief of the Prototype Branch, by R. G. McGee, Engineer, Prototype Evaluation Branch. Instrumentation support and development were provided by Mr. G. C. Downing, Chief of the Special Services Branch, Instrumentation Services (ISD), and Mr. B. G. Palmertree, ISD. Acknowledgment is made to the personnel of the Omaha District for their assistance in the development of this procedure. Mr. McGee was project coordinator for WES.

Commander and Director of WES during the development of this procedure and the preparation and publication of this report was COL Tilford C. Creel, CE. Technical Director was Mr. F. R. Brown.

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CHAPTER 2. EQUIPMENT

CHAPTER 3. SYSTEM ASSEMBLY

CHAPTER 4. PROCEDURE

CHAPTER 1

INTRODUCTION

1-1. Purpose and Scope

This manual describes and illustrates the step-by-step procedures involved in conducting pressure-momentum discharge tests. Instructions outlining the system assembly are given; however, detailed instrumentation specifics are beyond the scope of this text. This information is given in the system manuals of each component.

1-2. Background

The pressure-momentum method of discharge measurement is a proven method used only in a pipe or closed conduit that has a valve or some other means of shutting off the flow of water. The method is particularly adapted to measuring the discharge in long, freestanding penstocks in which the flow of water is controlled by turbine gates.

1-3. Basic Theory

a. The method described herein is a modification, developed at the U. S. Army Engineer Waterways Experiment Station (WES), of the Gibson Method.* Much material pertaining to the development of the Gibson Method is presently available; therefore a detailed theoretical investigation into this method will not be included in the manual. Instead, the following abbreviated derivation of the Gibson, or pressure-momentum, Method is presented.

b. As shown in Figure 1-1, the pressure-momentum test section consists of two penstock piezometer rings (P1 and P2) located upstream of the gate. As the gate is closed, the changing differential pressure between the piezometers is recorded, producing a differential pressure-time curve similar to that shown in Figure 1-2. The area under this pressure-time curve is proportional to the discharge prior to gate closure.

c. According to Newton's second law of motion, $\Sigma F = ma$. For this procedure, only the forces in the horizontal (x) direction are considered, i.e.,

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* N. R. Gibson. 1923. "The Gibson Method and Apparatus for Measuring the Flow of Water in Closed Conduits," Transactions, American Society of Mechanical Engineers, Vol. 45.

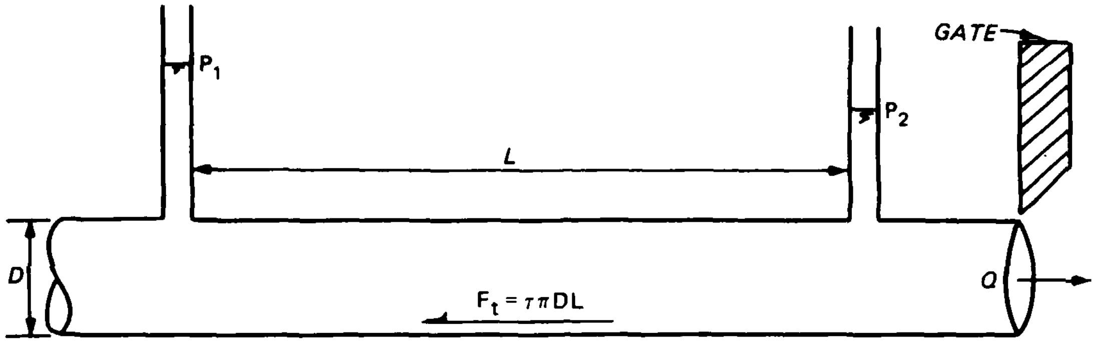


Figure 1-1. Pressure-momentum test section

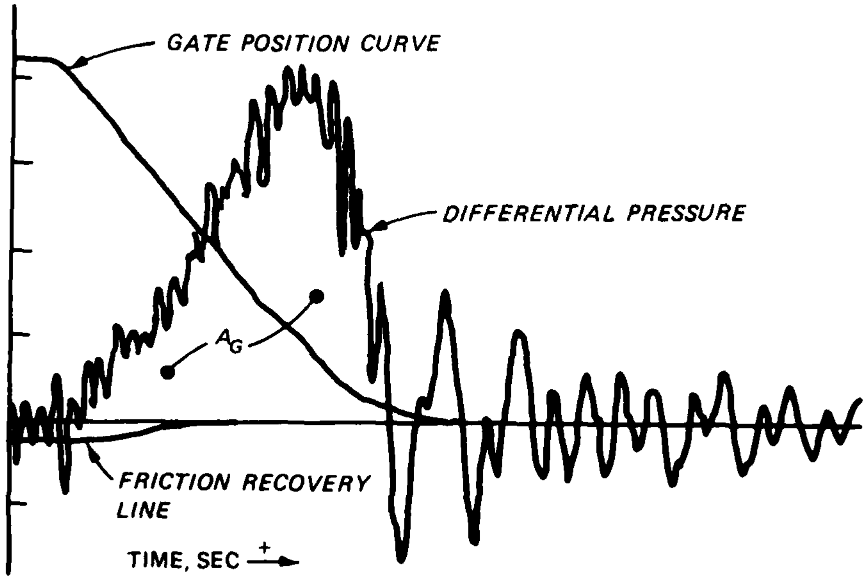


Figure 1-2. Differential pressure-time curve

$\overset{+}{\leftarrow}\Sigma F_x = ma_x$. First, sum all the forces acting on the test section during gate closure and define the terms for mass and acceleration as in Equations 1, 2, and 3.

$$\Sigma F_x = (P1 - P2)\ \frac{\pi D^2}{4} + \tau\pi DL \tag{1}$$

$$\text{Mass (m)} = W/g = \frac{\gamma\pi D^2 L}{4g} \tag{2}$$

$$\text{Acceleration } (a_x) = dv/dt \tag{3}$$

where

(P1-P2) = (ΔP) = differential pressure during gate closure, psid

D = penstock diameter, ft

τ = shear stress on penstock wall, lb/ft^2

L = length of test section, ft

W = weight, lb

g = gravitational acceleration, ft/sec^2

γ = specific weight of water, lb/ft^3

dv/dt = derivative of velocity with respect to time (ft/sec^2)

By substituting Equations 1, 2, and 3 into $\overset{+}{\leftarrow}\Sigma F_x = ma_x$, the following relationship is obtained.

$$(\Delta P)\ \frac{D}{4} + \tau L = \frac{\gamma DL}{4g}\ \frac{dv}{dt} \tag{4}$$

Multiply Equation 4 by 4/D and integrate according to Equation 5.

$$\int_{t=o}^{T} \Delta P + \frac{4\tau L}{D}\ dt = \frac{\gamma L}{g} \int_{V1}^{V2} dv \tag{5}$$

The left side of the equation is integrated from the beginning of gate closure (t=o) to complete closure of the gate (t=T). This represents the area under the pressure-time curve (A_G of Figure 1-2). The right side of Equation 5 is integrated from the initial velocity (V1) to the final velocity (V2). The final velocity in this case is the velocity at gate closure (V2=0). By integrating and solving Equation 5 for the discharge (Q), the basic form of the pressure-momentum equation is obtained.

$$Q = (V1)A = \frac{A_G g A}{L} \tag{6}$$

where

A_G = area under pressure-time curve

A = cross-sectional area of test penstock

d. The method developed at WES consists of an electronic data acquisition system programmed to perform these calculations concurrent with data collection.

CHAPTER 2

EQUIPMENT

2-1. System Components

The WES Data Acquisition and Control System (DACS) used in conducting the pressure-momentum test consists of the following major components:

a. Control unit and microprocessor

b. Differential pressure transducer

c. Gate opening potentiometer

d. Calibration manometer

e. Analog plotter

f. Printer

A schematic showing how the major components listed above are integrated into the complete system is given in Figure 2-1.

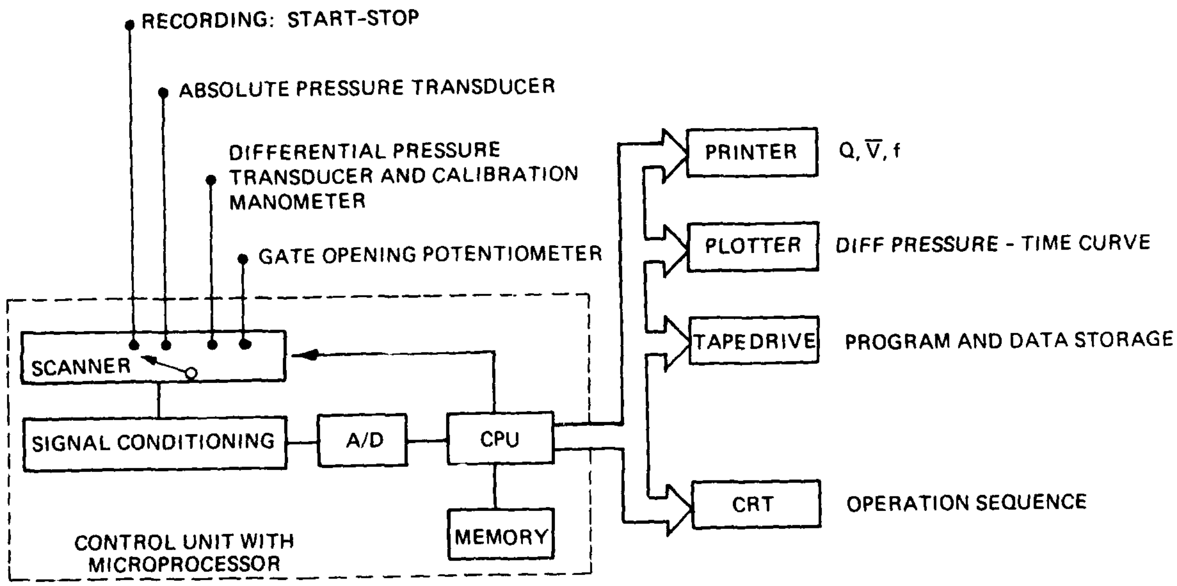


Figure 2-1. WES Data Acquisition and Control System

2-2. Control Unit and Microprocessor

The control unit and microprocessor shown in Figure 2-2 controls the DACS. This unit has been interactively programmed so that sequential operation commands guide the operator through the test. A complete program listing is given in Appendix C. Signals from all data sources are transmitted to the microprocessor to be digitized, stored, and analyzed. The analysis involves integrating the differential pressure data over the period of time required to close the gates. This includes an iterative numerical analysis that makes an adjustment to the area due to the recovery of friction losses during gate closure (see Figure 1-2). This is a converging process; therefore it takes a number of computational iterations to determine the actual discharge. Each iteration is listed in the output. An example of the output is given by Plate D3 of Appendix D.

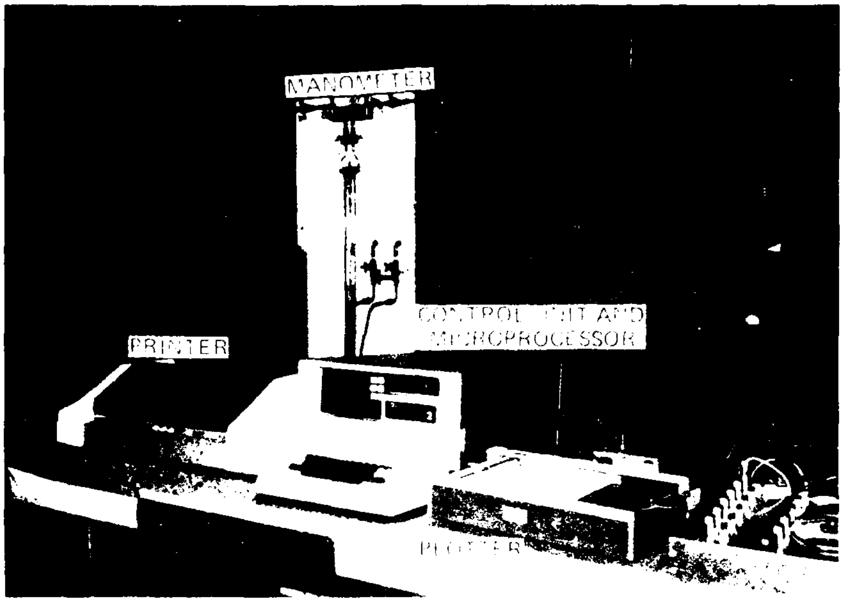


Figure 2-2. Calibration manometer, printer, plotter, and microprocessor

2-3. Differential Pressure Transducer

The "heart" of the DACS is the differential pressure transducer shown in Figure 2-3. It is connected by nonflexible pressure conduit to the piezometer rings located on the penstock upstream of the gates. The transducer is also connected in parallel with a manometer (Figure 2-2) used to conduct the transducer calibration and periodic calibration checks throughout the test program. Pressures are set on this calibration system by opening and closing certain combinations of valves. The calibration section (paragraph 4-2) gives step-by-step instructions for valve operations during calibration. Each valve is referred to by number and Figure 2-4 gives a schematic diagram of the calibration system explaining the piping scheme used and showing the valves and their

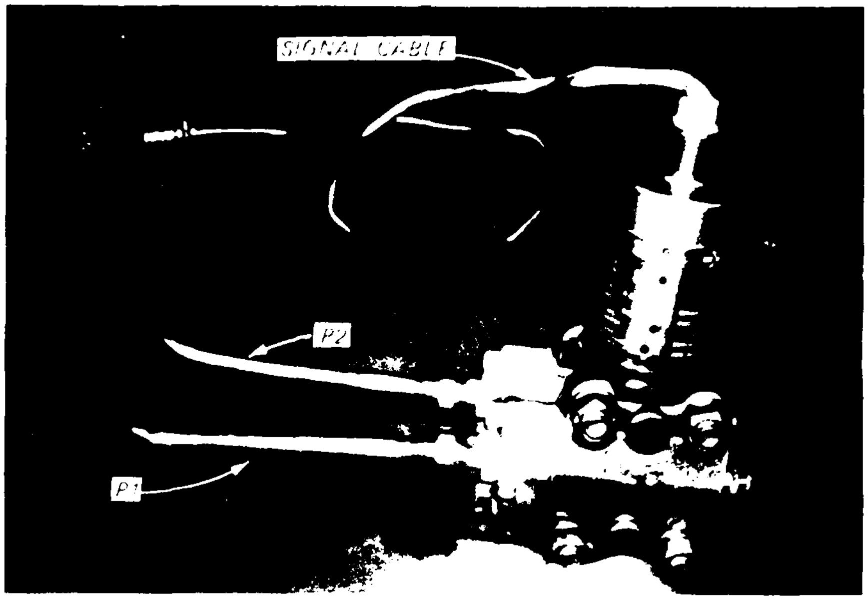


Figure 2-3. Differential pressure transducer

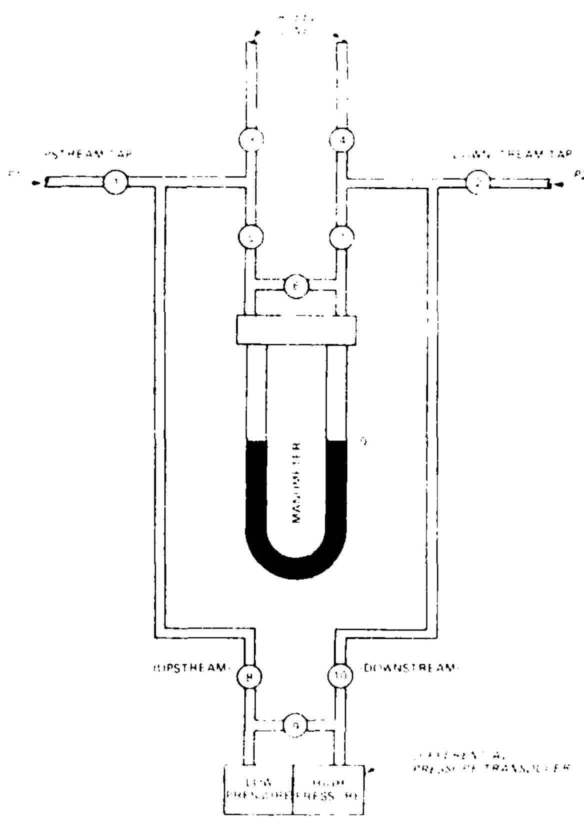


Figure 2-4. Calibration system diagram

identification numbers. This diagram will be referred to throughout the manual.

2-4. Gate Opening Potentiometer

A potentiometer (Figure 2-5) is attached to the servomotor of the wicket gates to record gate position during each test. These data are recorded simultaneously with the differential pressure data to give accurate readings of gate position with respect to time. Plate D5 shows a sample plot of the gate position data (see also Figure 1-2).

2.5. Absolute Pressure Transducer

An absolute pressure transducer is attached to the penstock to measure the absolute pressure acting upstream of the gates during gate closure. Although these data are quite useful, they are not used in the discharge calculations. These data are recorded simultaneously with all other data. Plate D6 shows a sample plot of the absolute pressure data.

Figure 2-5. Gate opening potentiometer

2-6. Output Peripherals

Test results are output by an alphanumeric line printer and an analog data plotter. The printer lists the results and provides tabulations of the digitized data. The plotter provides time-history plots of the data for field inspection of the results.

CHAPTER 3

SYSTEM ASSEMBLY

3-1. General Requirements

The DACS is designed to connect directly to existing Gibson piezometer manifolds. Therefore the only plumbing need is 1/2-in.-inside-diameter non-flexible pressure conduit (lengths may vary between projects) with the proper connectors to couple the DACS to the piezometers. The system requires an adequate source of power, electrical outlets, and extension cords. Also, the recording area requires approximately 40 sq ft of table top area (two tables) for the instrumentation hardware and adequate seating and lighting for personnel.

3-2. Assembly Instructions

The DACS is a portable system requiring a minimal amount of assembly time. The system can be unpacked and assembled in approximately 1 hr. Specific hardware instructions are provided by the manuals for each component. Appendix B lists each component and its manufacturer or service representative. Figure 3-1 is a diagram presenting the assembly procedure with numbers matching the following assembly steps:

1. Assemble microprocessor and control system hardware.
   - a. Assemble MACSYM and keyboard (refer to system hardware manual).
   - b. Connect the signal cable from the printer to the MACSYM. The printer cable is interconnected at communication card ACPØ4 in the MACSYM card cage (refer to Figure 3-2).
   - c. Connect the signal cable from the analog plotter to the MACSYM. The plotter cable interconnection is made at the analog output (AOT) card located in slot 2 of the card cage (refer to Figure 3-2).
   - d. Connect the WES-fabricated transducer cable interface box (Figure 3-3) to the MACSYM. This is interconnected at the analog input (AIN) card located in card slot 1 of the card cage.

2. Assemble calibration system.

   Note: The calibration system must be completely sealed. There should be no leaks at any of the connections or valves.

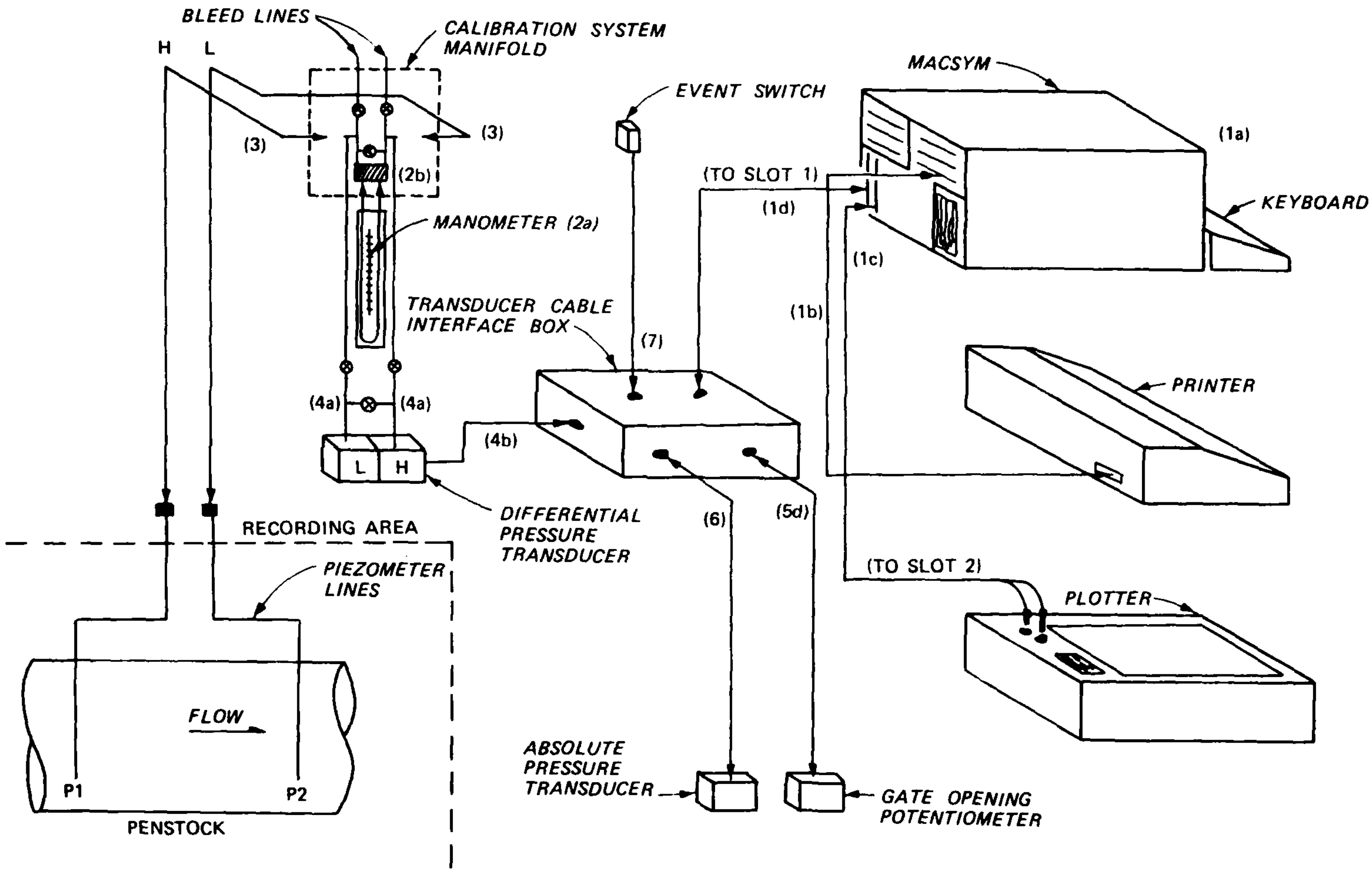


Figure 3-1. System assembly diagram

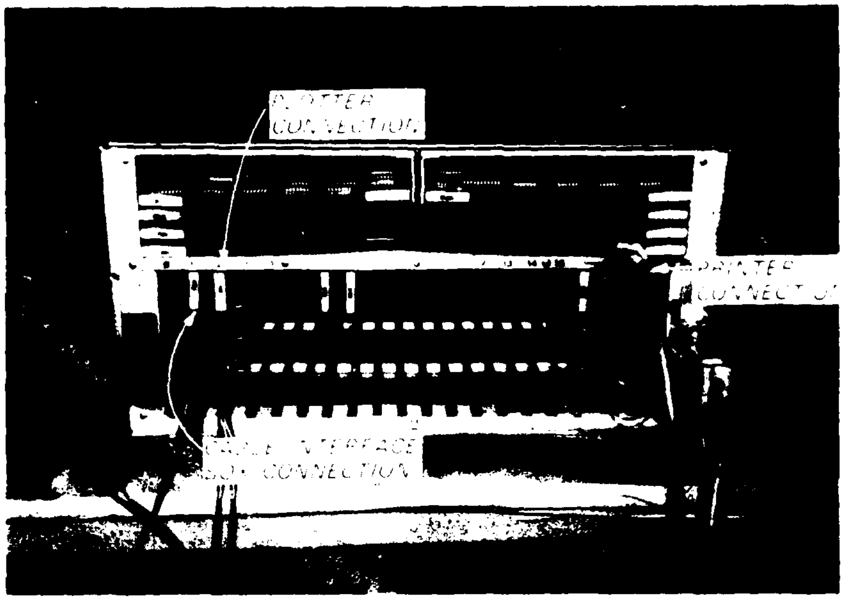


Figure 3-2. MAC-1 card cage

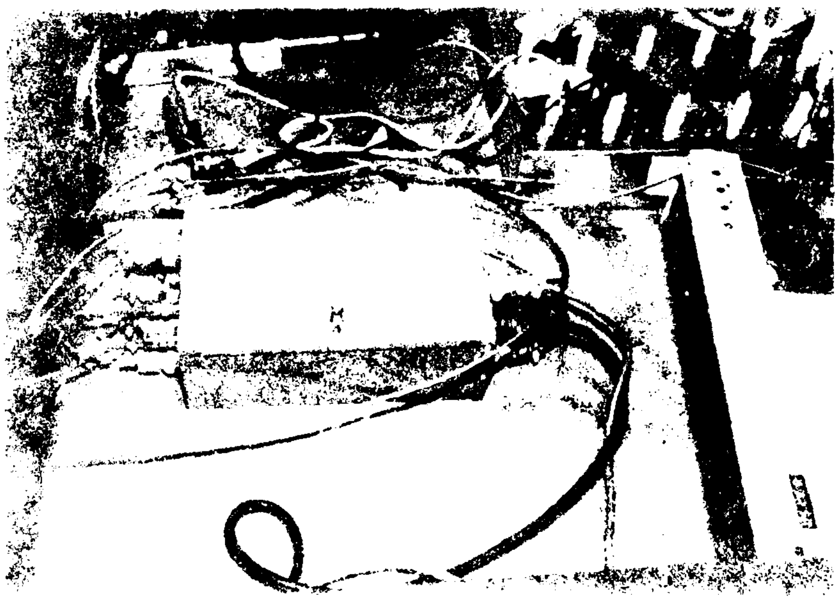


Figure 3-3. WES-fabricated cable interface box

a. Fill manometer U-tube to zero level with indicator fluid and fill the remainder of the tube with water.

b. Connect U-tube to manometer head of the calibration system valve manifold. Tighten wing nut securely.

3. Connect the calibration system to the piezometers with nonflexible piping. Connect the upstream (high pressure) piezometer tap with manometer manifold valve 1 and the downstream (low pressure) piezometer tap with manifold valve 2.

4. Connect differential pressure transducer.
   a. The differential pressure transducer is coupled to the piezometers at valves 8 and 10 on the calibration system. At this point, the pressure lines are connected in reverse. The upstream valve 8 is connected to the low-pressure side of the transducer while the downstream valve 10 is connected to the high-pressure side of the transducer. Figure 3-4 shows the assembled calibration system.
   b. Connect the transducer signal cable with the cable interface box at the designated connector.

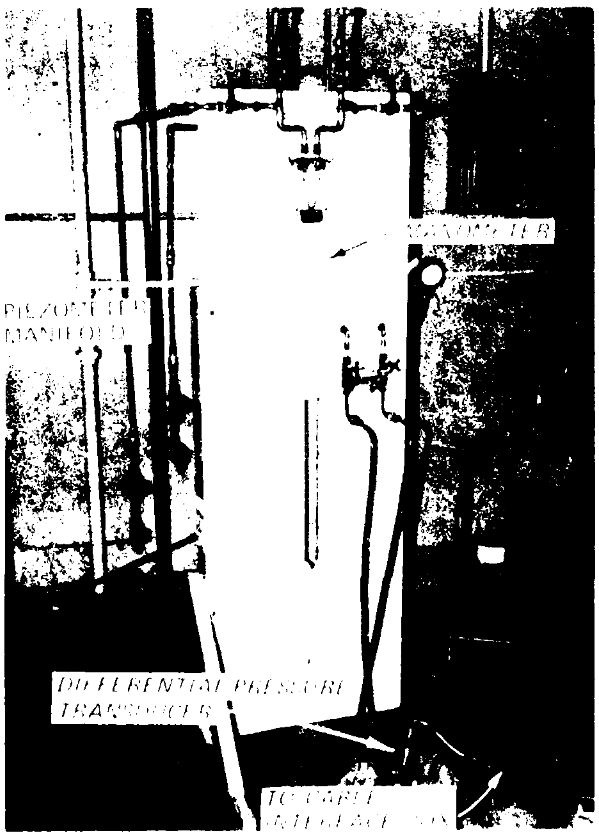


Figure 3-4. Assembled calibration system (manometer and differential pressure transducer)

5. Assemble gate opening potentiometer.

   a. Attach potentiometer to mounting bracket.

   b. Attach bracket to servomotor.

   c. Hook the sensing wire of the potentiometer to the governor restoring cable mount. Be sure the wire is level and can be extended over 100 percent of the piston stroke (refer to Figure 2-5).

   d. Run the potentiometer signal cable to the recording area and interconnect with the cable interface box at the designated connector.

6. Install absolute pressure cell and interconnect the signal cable with the cable interface box at the designated connector.

7. Connect the event switch to the cable interface box.

CHAPTER 4

PROCEDURE

4-1. General

a. This chapter outlines the procedure for calibration of all transducers, provides step-by-step instructions for conducting the pressure-momentum tests, and gives instructions for reducing and analyzing previously recorded data. The procedure for the pressure-momentum method is divided into six routines:

(1) Calibration

(2) Input of known properties

(3) Zero data collection

(4) Calibration check

(5) Steady-state data collection

(6) Test data collection

Except for the calibration and calibration check routines, all steps are repeated for each test. Figure 4-1 shows a procedural flowchart outlining the general order of testing.

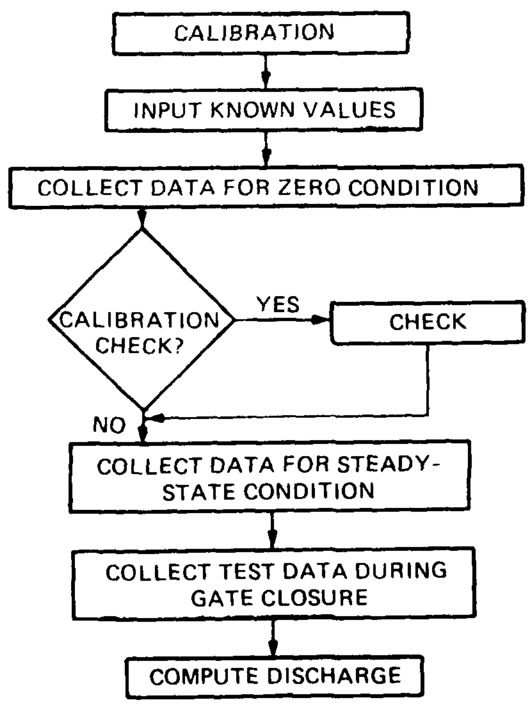


Figure 4-1. Procedural flowchart

b. The Control Unit guides the operator through the procedure with sequential operational commands appearing on the unit's CRT. Data collection is actuated by depressing an "event" switch. The Control Unit indicates when to use the event switch. Detailed instructions of the use of this switch are given in the test procedure section of this manual.

c. All procedures are performed with the same computer program. Load the program according to the following steps:

1. Insert the MACBASIC system master cartridge into the cartridge drive.
2. Press RESET and then LOAD (the AUTO button must not be pressed).
3. MACSYM will load the system programs from the cartridge and respond:

   MULTITASK BASIC REV. X.X

   DATE (M/D/Y)?

   If you wish, you may use only the carriage RETURN key which will automatically set a default date of 1/1/79 and a time of ØØ:ØØ:ØØ and go to step 4.0; type the current date with either spaces or slashes between the month, the day, and the year. Then press RETURN, and the following will be displayed:

   TIME (H:M:S)?

   If you depress the carriage RETURN only, the system clock will be initialized to ØØ:ØØ:ØØ. If desired, type the current time in 24-hr format with colons or spaces after the hour and the minutes, followed by a carriage RETURN.
4. MACSYM will respond:

   READY

   and is ready for you to execute BASIC.
5. Bring into memory the source program (Pressure-Momentum Test Program) using the following format:

   COMPILE MTØ:Ø.
6. After the program has been entered into memory, initialize the program by simply typing RUN followed by a carriage RETURN.

4-2. Calibration

The calibration procedure determines the constants used in the discharge computations. These constants are used in converting electrical signals produced by the transducers into appropriate engineering units. Calibration constants for zero gate position, percent gate opening, penstock differential pressure, and penstock absolute pressure are required for each test. Procedural steps for determining these factors are outlined below. Subroutines have been included in the program to assist the operator in determining these factors. An example calibration sheet is given as Plate D1.

1. Zero Gate Position. This value, measured in volts, represents gate closure. Completely close the turbine gates and enter the command RUN 8000 into the Control Unit. Input the appropriate channel number and read the corresponding voltage. Record this value in the appropriate block (1) of the referenced calibration sheet.
2. Percent Gate Opening. This factor is used to convert the voltage output from the gate opening potentiometer into units of percent gate opening. Set the gates at a known opening and enter the command RUN 8000 into the Control Unit. Input the appropriate channel number and read the corresponding voltage. Record these values in columns (2) and (3) of the calibration sheet. Repeat this procedure for several gate openings until adequate linearity has been determined. Calculate the calibration factor for each gate opening as shown in Plate D1 and determine the average value for use as the percent gate opening calibration factor.
3. Differential Pressure. This factor is used to convert the voltage output of the differential pressure transducer into units of pounds per square inch (differential). During a test, the differential experiences both positive and negative pressures. Therefore the transducer calibration should range from the maximum expected positive pressure to the maximum expected negative pressure. The manometer deflections corresponding to positive and negative differentials are shown in Figure 4-2.
   (a) First, establish a zero differential pressure condition on the system by opening the crossover valves for the manometer (6) and the transducer (9) (Figure 2-4). Close valves 1, 2, 3, and 4 to prevent any flow conditions or pressure fluctuations that could affect the calibration. When zero has been established, enter the command RUN 8000 into the Control Unit, input the appropriate channel number, and read the corresponding voltage. Record this value in the appropriate block (1) of the calibration sheet. In summary, for determining the voltage at zero pressure differential the valve settings of Figure 2-4 should be as follows:

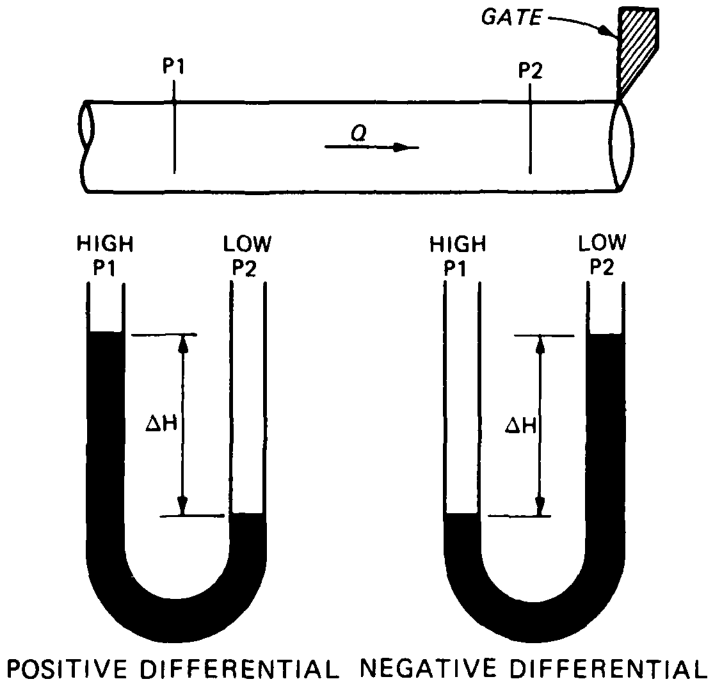


Figure 4-2. Manometer deflections

ZERO DIFFERENTIAL PRESSURE

VALVE POSITION (Figure 2-4) OPEN	CLOSED
5, 6, 7, 8, 9, 10	1, 2, 3, 4

(b) Set the valves to calibrate by negating the zero pressure differential. Do this by slowly opening the entrance valves (1 and 2). Next, close the crossover valves for the manometer (6) and the transducer (9).

CALIBRATION DIFFERENTIAL PRESSURE

VALVE POSITION (Figure 2-4) OPEN	CLOSED
1, 2, 5, 7, 8, 10	3, 4, 6, 9

(c) Begin the calibration by setting on the system the highest expected positive differential pressure. A positive differential (Figure 4-2) is set by releasing pressure on the high (upstream) side of the manometer. Do this by slowly opening the high side bleed valve (3) until the desired differential is reached. Be careful not to let the indicating fluid get too high and blow out of the manometer. When the differential is reached, shut off the low (downstream) pressure side by quickly closing the low side entrance valve (2). Next, close the open bleed valve (3). Finally, to assure a nonfluctuating pressure reading, close the high side entrance valve (1).

POSITIVE CALIBRATION DIFFERENTIAL

(Refer to Figure 2-4)

1. Open 3 slowly
2. Close 2 quickly
3. Close 3
4. Close 1

(d) Read the manometer deflection and convert to differential pressure using the appropriate conversion factor listed in Table A1. Next, read the transducer output voltage by entering the command RUN 8000 into the Control Unit and inputting the channel number desired. Read the corresponding voltage and record these values in the appropriate columns (2) and (3) of the referenced calibration sheet.

(e) By starting with the highest pressure, a number of points can be determined without repeating the above procedure. With the supply valves (1 and 2) still closed, set a smaller differential pressure by simply opening a crossover valve (either 6 or 9). Close the valve when the desired pressure is reached. A number of different pressures can be set before the differential equalizes at zero; a minimum of 10 points is suggested to establish linearity.

(f) After the positive differential pressures have been recorded, repeat this procedure using negative (Figure 4-2) differential pressures. Begin by repeating the procedures of Steps 3(a) and 3(b). Then set the highest expected negative pressure and reduce in steps until the pressure again equalizes at zero. A negative differential is set by releasing pressure on the low (downstream) side of the manometer. Do this by slowly opening the low side bleed valve (4) until a desired differential is reached. Be careful not to let the indicating fluid get too high and blow out of the manometer. When the differential is reached, shut off the high (upstream) pressure side by quickly closing the high side entrance valve (1). Next, close the open bleed valve (4). Finally, to assure a nonfluctuating pressure reading, close the low side entrance valve (2). Again, a minumum of 10 points is suggested.

NEGATIVE CALIBRATION DIFFERENTIAL

(All valves open except 3, 4, 6, 9, see Figure 2-4)

1. Open 4 slowly
2. Close 1 quickly
3. Close 4
4. Close 2

(g) A calibration factor is determined for each calibration run as shown in Plate D1. After all calibration runs have been completed, the average calibration factor should be calculated and recorded.

4. Absolute Pressure. The absolute pressure transducer is calibrated independently by the most readily available means. The pressure transducer should be adjusted to the best-suited scale factor.

4-3. Test Procedure

Begin the test procedure by entering a RUN command.

1. PROJECT = ______________________________

Input the project name.

2. DO YOU WANT TO REDUCE STORED DATA? (YES OR NO)

Enter NO if an actual test is to be run and continue with the next step in the procedure. Enter YES and go to paragraph 4-4 for instructions in retrieving and analyzing stored data.

3. WHAT IS THE TURBINE #?

Enter the unit number of the turbine to be tested. This entry must be input in numerical form.

4. DATE (M/D/Y)?

Enter the month, day, and year in the manner specified.

5. TIME (H:M:S)?

Enter the present time in hours, minutes, and seconds in the specified format. Use 24-hr military time.

6. REPLACE PROGRAM CARTRIDGE WITH CLEAN DATA CARTRIDGE

If the data are to be retained, an empty data cartridge should be placed in the Control Unit. Note: One cartridge will store the data for five tests.

7. PENSTOCK DIAMETER IN FT = ______________________________

Enter an accurate measurement of the inside diameter of the test penstock in units of feet.

8. DISTANCE BETWEEN PIEZOMETER RINGS IN FT = ________________________

Enter the length along the center line of the penstock between the two piezometer rings in feet. This distance should be determined as accurately as possible.

9. WATER TEMPERATURE IN DEGREES F = ______________________________

Enter the temperature of the water flowing in the penstock in degrees Fahrenheit.

10. WATER DENSITY IN SLUGS/CU FT = _____________________________

Enter the appropriate value of water density (slugs/cu ft) corresponding to temperature of water flowing in the penstock. Refer to Table A2.

11. DIFFERENTIAL PRESSURE (PSI/VOLT) = ____________________________

Enter the calibration factor determined during the initial calibration for the differential pressure transducer.

12. ABSOLUTE PRESSURE (PSI/VOLT) = ______________________

Enter the calibration factor determined during the initial calibration for the absolute pressure transducer.

13. ZERO GATE POSITION (VOLTS) = ______________

Enter the voltage corresponding to zero percent gate opening determined during the initial calibration procedure.

14. PERCENT GATE OPENING (PERCENT OPENING/VOLT) = ________________

Enter the calibration factor determined during the initial calibration for the gate opening potentiometer.

15. EXPECTED DURATION OF TEST IN SEC = ________________

Input the maximum amount of time to be allotted for data collection, preferably no more than 40 sec to ensure an adequate data sampling rate. This value may be used as the computational endpoint instead of the event switch since data are collected during the entire time span established by this value. Depressing the event switch at the end of a run only tells the Control Unit how much of the collected data to use in the discharge calculations. It has no bearing on the amount of data collected. Therefore, if it is desirable to use all collected data (i.e., time of EXPECTED DURATION) in the calculations, the operator should not use the event switch to end the test.

16. TEST # = ________________

Input the number corresponding to each individual test run. This is to provide further identification for each test.

17. MANUAL ENTRIES COMPLETED

The remainder of the procedure involves collecting the test data. Collection of required data is actuated by depressing the event switch. The computer will notify the operator to depress the event switch at the appropriate time during the procedure. To ensure accurate pressure readings, make certain the system is bled of all entrapped air.

18.a. SET TRANSDUCER VALVES IN POSITON TO GET ZERO DIFFERENTIAL PRESSURE

Refer to Step 3(a) of the calibration section.

ZERO DIFFERENTIAL PRESSURE VALVE POSITION	
OPEN	CLOSED
5, 6, 7, 8, 9, 10	1, 2, 3, 4

18.b. PUSH EVENT SWITCH WHEN READY TO TAKE DATA FOR ZERO CONDITION

Actuate the zero data collecting process by depressing the event switch.

19. DO YOU WANT TO CHECK CALIBRATION?

Steps 20.a. through 20.e. are provided to check the differential pressure transducer calibration. The transducer scale factor is checked by comparing a differential pressure read by both the manometer and the pressure transducer. If a check is desired, input YES. If the user is confident the calibration factors are still accurate, this portion of the procedure may be omitted by inputting NO and proceeding to Step 21. It would be wise, though, to periodically check the calibration factors to ensure that the data are being properly collected.

20.a. SET VALVES IN POSITION TO CALIBRATE D/P TRANSDUCER.

Refer to Step 3(b) of the calibration section.

CALIBRATION VALVE POSITION	
OPEN	CLOSED
1, 2, 5, 7, 8, 10	3, 4, 6, 9

20.b. SET CALIBRATION DIFFERENTIAL

Set either a positive or negative differential pressure on the system (refer to Step 3(c) of the calibration section).

POSITIVE CALIBRATION DIFFERENTIAL	NEGATIVE CALIBRATION DIFFERENTIAL
(Figure 2-4)	
1. Open 3 slowly	1. Open 4 slowly
2. Close 2 quickly	2. Close 1 quickly
3. Close 3	3. Close 4
4. Close 1	4. Close 2

20.c. PUSH EVENT SWITCH WHEN CONDITIONS ARE READY TO TAKE CALIBRATION DATA

When the desired differential has been "locked in," depress the event switch to record the transducer output voltage. The operator should also read the manometer and convert the differential in inches to pounds per square inch differential (PSID).

20.d. MANOMETER READING IN PSI FOR THIS RUN = ____________________

Input the differential pressure reading of the manometer. This value is compared with the transducer to check the transducer scale factor. If the readings compare to within 0.5 percent the computer will proceed to Step 21. If the readings do not compare to within 0.5 percent the following statement will appear on the CRT.

MANOMETER DOES NOT AGREE WITH TRANSDUCER SCALE FACTOR

P1 = ____value____

P2 = ____value____

ERROR = ____value____

Where: P1 is the differential pressure transducer reading.

P2 is the manometer reading.

ERROR is the percent error of P1 as compared with P2.

20.e. DO YOU WANT TO CONTINUE USING THIS MANOMETER CALIBRATION (YES OR NO)

If the percent error between the differential pressure transducer and manometer readings is still considered to be within acceptable limits, this manometer calibration may continue to be used. If the percent error is not acceptable, a response of NO will repeat the calibration procedure (return to Step 20.a.)

Note: If after several repetitions the error continues to exceed the desired accuracy, the differential pressure transducer should be recalibrated.

21.a. CALIBRATION DATA COMPLETE
SET VALVES IN TEST POSITION
TAKE FLOW TO STEADY-STATE CONDITION

Open the crossover valves (6 and 9) to release the calibration differential. Open entrance valves (1 and 2) and bleed the system to ensure that all lines are free of entrapped air. Prepare the system to take steady-state data by closing the manometer entrance valves (5 and 7) and the transducer crossover valve (9). This takes the manometer off-line and establishes both steady-state and test conditions.

TEST VALVE POSITION

OPEN	CLOSED
1, 2, 8, 10	3, 4, 5, 7, 9

21.b. PUSH EVENT SWITCH WHEN FLOW IS STABLE

Allow ample time after each test for flow in the penstock to stabilize. When flow has stabilized depress the event switch (Figure 4-3) to take data for steady-state conditions.

22. UPPER POOL = ________________

Enter the upper pool elevation.

23. LOWER POOL = ________________

Enter the lower pool elevation.

24. COMPUTER IS READY TO TAKE TEST DATA FOR TEST #__________.
PUSH EVENT SWITCH WHEN GATES START TO CLOSE

The test valve positons were set up in Step 21.a. Actuate the data recording by depressing the event switch when the gates start to close (Figure 4-3). Control Unit will record data until the event switch is

Figure 4-3. Actuation of data collection

depressed again or until the expected duration of the test is reached (refer to Step 15). The statement TEST DATA FOR TEST # ________ IS COMPLETE will appear upon completion of the data collecting. The microprocessor will then begin digitizing and reducing the data.

Note: (a) The statement MEMORY OVERFLOWED BEFORE END OF TEST appears when a stop signal from the event switch is not received by the Control Unit before all data storage registers are filled. In other words, the Control Unit automatically stops data recording when the input expected test duration (Step 15) is reached.

(b) DO YOU WANT TO CONTINUE (YES OR NO). If sufficient data have been recorded (i.e., gates closed before data collection was halted) the operator may want to continue reducing the data. Therefore input YES. However, sufficient data may not have been recorded and the test may be aborted by entering NO and proceeding to Step 28 of the procedure.

25.a. DO YOU WANT TO SAVE THE DATA (YES OR NO)

The data may be stored on data cartridges for future reference. Input YES if the data are to be retained. If not, input NO and proceed to Step 27.

25.b. INPUT FILE NAME FOR DATA (MTØ:n)

INPUT FILE NAME FOR VARIABLES (MTØ:n+1)

The data and the variables are stored sequentially on the data cartridges beginning with location n=0. Each cartridge will store approximately five tests. An example is given below.

TEST #	ITEM	STORAGE LOCATION
1	Data	MTØ:Ø
	Variables	MTØ:1
2	Data	MTØ:2
	Variables	MTØ:3
3	Data	MTØ:4
	Variables	MTØ:5
4	Data	MTØ:6
	Variables	MTØ:7
5	Data	MTØ:8
	Variables	MTØ:9

26. DO YOU WANT TO PLOT THE DATA?

Plotting routines have been included to provide a variety of data plots allowing the user to visually check the results. Explanations of the different plots are given below and samples of each are shown in Plates D5 and D6 of Appendix D. Reply YES or NO as to whether or not plots are desired. YES, go to Step 26.a; NO, go to Step 27.

Note: If stored data from an earlier test are being reduced, a response of NO will bypass the data plotting and proceed to the computations (see paragraph 4-4, Step 4).

Plotting Routine

a. WHICH CHANNEL (1,2,3,4,5)?

(1) = Differential Pressure. This is a plot of the pressure-time diagram generated during gate closure (Plate D5).

(2) = Gate Position. This is a plot of gate position versus time (Plate D5).

(3) = Absolute Pressure. This is a pressure-time diagram of the absolute pressure in the penstock during gate closure (Plate D6).

(4) = Area Accumulation (No Friction). This is a plot of the calculated area-under-the-curve summation before the friction recovery line is calculated (Plate D5).

(5) = Area Accumulation (Friction Calculated). This is a plot of the calculated area-under-the-curve summation with the friction recovery line calculated. In order to generate this plot, the entire discharge calculation must be performed. Upon completion of this plot, the plotting routine will be exited and the procedure forwarded to Step 27.

b. SET ZERO ON X-Y PLOTTER AND TYPE (CR)

Use zero control knob on plotter panel to set the zero position.

c. SET GAIN ON X-AXIS FOR 9

SET GAIN ON Y-AXIS FOR 3

TYPE (CR)

Set the gains at the indicated position on the graph with the range control knobs.

d. SCALE FACTOR FOR X-AXIS = ____________

SCALE FACTOR FOR Y-AXIS = ____________

Enter the appropriate scale factors as given in Table A3.

e. SET PEN IN DOWN POSITION AND TYPE (CR)

With the pen in the down position, type a carriage return to actuate the plotter. The DACS will return to Step 26 after each plot.

27. DO YOU WANT A TABULATION OF DATA (YES OR NO)

a. YOU HAVE ________ LINES OF DATA

HOW MANY DO YOU WANT TO TABULATE?

A maximum of 600 lines of digitized data are generated for each test. The user may list as much of these data as he wishes. For example, an input of 100 would output every sixth line of data. A sample of this tabulation is shown by Plate D4.

b. DO YOU WANT ANY MORE TABULATIONS?

YES Return to Step 27.a.

NO. Proceed to Step 28.

28. ARE THERE ANY MORE TESTS? (YES OR NO)

YES. Proceed to Step 29.

NO. Testing is complete.

29. ARE MANUAL ENTRIES THE SAME AS FOR THE PREVIOUS TEST? (YES OR NO)

If the known properties input for the previous test are unchanged, enter YES and return to Step 15 of the procedure. However, if any of the manual entries have changed, enter NO and return to Step 1.

Note: Enter NO if the tabulation or plotting of previously stored data is desired.

4-4. Stored Data Reduction

This procedure is initialized at Step 1 of the test procedure (paragraph 4-3).

1. FILE NAME FOR DATA (MTØ:n)

FILE NAME FOR VARIABLES (MTØ:n+1)

Data stored on data cartridges can be retrieved for analysis by inputting the appropriate file names for the data and the variables of each test. Make certain to use the format shown in the parentheses above.

2. DO YOU WANT TO CHANGE THE DURATION OF THE TEST? (YES OR NO)

NO. Go to Step 26 of the test procedure section.

YES. Proceed to Step 3.

3. THE EXPECTED DURATION OF THIS TEST = _________ SECONDS

   THE COMPUTATION END POINT FOR THIS TEST = __________ SECONDS

   DURATION CHANGE IN SEC = $\underline{\pm\Delta \text{Time}}$

   Change the computational end point by inputting the desired time change. This change is applied algebraically to the computation end point shown above. Therefore indicate with a (+) or (-) whether the change is added to or subtracted from the end point. Go to Step 26 of the test procedure.

4. DO YOU WANT TO CONTINUE REDUCING DATA? (YES OR NO)

   YES. Will compute the discharge, generate the output, and then proceed to paragraph 4-3, Step 25.a.

   NO. Proceed to paragraph 4-3, Step 25.a.

APPENDIX A

CONVERSION FACTORS AND TABLES

Table A1

Manometer Conversion Factors

Water Temperature °F	Inches Deflection/psid, B Mercury, Hg	*Meriam, Me
32	2.202	14.194
40	2.202	14.197
50	2.203	14.199
60	2.204	14.208
70	2.207	14.224
80	2.209	14.242
90	2.213	14.267

Note: To convert Δh in inches to differential pressure (psid): psid = $\frac{\Delta h}{B}$

* Specific gravity of Meriam = 2.95.

Table A2

Water Density*

Temperature °F	Density slugs/ft^3
32	1.940
40	1.940
50	1.940
60	1.938
70	1.936
80	1.934
90	1.931
100	1.927
110	1.923
120	1.918

* Fluid Mechanics for Engineers, Prentice-Hall, Inc., 1961.

Table A3

Suggested Plot Scale Factors

Time		Differential Press.		Absolute Pressure			Gate Opening		Area Accumulation	
*Range sec	X-Axis	*Range psid	Y-Axis	Range, psi High	Range, psi Low	Y-Axis	*Range Percent	Y-Axis	*Range psi-sec	Y-Axis
≤1	0.2	≤1	0.5	70	35	5.0	0-10	5	≤1	0.2
2-3	0.4	2-3	1.0				11-30	10	2-3	0.5
4	0.5	4-6	2.0				31-60	20	4-5	1.0
5-8	1.0	7-9	3.0				61-100	25	6-11	2.0
9-17	2.0	10-12	4.0						12-17	3.0
18-25	3.0	13-15	5.0						18-23	4.0
26-30	4.0	16-18	6.0						24-30	5.0
30-40	5.0	19-21	7.0							
		22-24	8.0							
		25-27	9.0							
		28-30	10.0							

* Range = highest value recorded during test.

APPENDIX B

DACS HARDWARE-MANUFACTURERS

1. Microprocessor and Control Unit
MACSYM 2, Model #MACØ2-21

Analog Devices, Inc.
385 University Avenue
Westwood, MA 02090
Phone: (617) 329-4700

Area System Specialists:

Analog Devices, Inc.
7271 Mars Drive
Huntington Beach, CA 92647
Phone: (714) 842-1717
Harold Weiss

Analog Devices, Inc.
123 E. Lake St., Suite 301
Bloomingdale, IL 60108
Phone: (312) 894-3300
Robert Koranda

Analog Devices, Inc.
Rt 1, Industrial Park
P. O. Box 280
Norwood, MA 02062
Phone: (617) 329-5804
John Redding

2. Printer

Anadex Grafixplus, Model DP9500, SN DØ78760

Anadex, Inc.
9825 DeSoto Avenue
Chatsworth, CA 91311
Phone: (213) 998-8010

3. Plotter

Hewlett Packard, X-Y Recorder, Model 7035B

Hewlett Packard
P. O. Box 1449
Kenner, LA 70063
Phone: (504) 467-4100

Hewlett Packard
7101 Mercy Road
Suite 101, IBX Building
Omaha, NE 68106
Phone: (402) 392-0948

4. Differential Pressure Tranducer

Model PD3000-100-52-11, 100 inches of water range
Model PD3000-400-52-11, 400 inches of water range

Gould, Inc.
Measurement Systems Division
2230 Statham Blvd.
Oxnard, CA 93030
Phone: (805) 487-8511

5. Position Displacement Transducer
   PT101-20A (20" Range)

   Celesco
   Environmental and Industrial Products Division
   7800 Deering Avenue
   Conoga Park, CA 91304
   Phone: (213) 884-6860

6. Data Cartridges
   Scotch DC 100A Certified Data Cartridge

   Purchasing House:
   Financial Automation, Inc.
   1770 The Exchange, Suite 270
   Atlanta, GA 30399
   Phone: (404) 256-5775

APPENDIX C

COMPUTER SOFTWARE

C1. Program Listing

```
10
20 PRINT "......PRESSURE MOMENTUM FLOW TEST......"
30 AIN(1,1,0,1) IS THE DIFFERENTIAL CELL
40 AIN(1,2,0,1) IS THE ABSOLUTE CELL
50 AIN(1,3,0,1) IS THE GATE POSITION
60 AIN(1,4,0,1) IS THE EVENT
70 PRINT
80 PRINT
90 N3=3600
100 DIM Z(N3), T(28)
110 DATA 1,2,1,3,1,4
120 DIM B(21),Q(21),F(21),V(21),D(21)
130 DIM A$(50) LOCATION
140 DIM O$(5),B$(6),C$(35)
150 DIM S$(10),TI$(10)
160 V=0
170 GOTO 230
180 INPUT " ARE MANUAL ENTRIES THE SAME AS FOR THE PREVIOUS TEST (YES OR NO) "O$
190 X=ASC(O$)
200 IF X=89 E9=2.0 GOTO 530
210 IF X=78 GOTO 230
220 GOTO 180
230 INPUT " PROJECT = "A$
240 INPUT " DO YOU WANT TO REDUCE STORED DATA  " O$
250 X=ASC(O$)
260 IF X=89 E9=1.0 GOTO 4170
270 IF X=78 E9=2.0 GOTO 290
280 GOTO 240
290 ON ERROR 122,300
300 INPUT " WHAT IS THE TURBINE #  "B
310 DATE
320
330 PRINT
340 PRINT " REPLACE PROGRAM CARTRIDGE WITH CLEAN DATA CARTRIDGE"
350 PRINT
360 ON ERROR 122,370
370 INPUT " PENSTOCK DIAMETER IN FT. = "D9
380 ON ERROR 122,390
390 INPUT " DISTANCE BETWEEN PIEZOMETER RINGS IN FT. = "L
400 ON ERROR 122,410
410 INPUT " WATER TEMPERATURE IN DEGREES F = "F2
420 ON ERROR 122,440
430
440 INPUT " WATER DENSITY IN SLUGS/CU.FT = "R0
450 ON ERROR 122,460
460 INPUT "DIFFERENTIAL PRESSURE TRANSDUCER (PSI/VOLT) = "F
470 ON ERROR 122,480
480 INPUT "ABSOLUTE PRESSURE TRANSDUCER (PSI/VOLT) = "E
490 ON ERROR 122,500
500 INPUT "ZERO GATE POSITION (VOLTS) = "Z3
```

```
510 ON ERROR 122,520
520 INPUT "PERCENT GATE OPENING (PERCENT OPENING/VOLT) = "J1
530 ON ERROR 122,540
540 INPUT " EXPECTED DURATION OF TEST IN SEC. = "T
550 ON ERROR 122,560
560 INPUT " TEST # = "N9
570 V=0
580 A=(PI*D9↑2)/4 PENSTOCK AREA
590 A2=A↑2 A3=A*144
600 PRINT " MANUAL ENTRIES COMPLETED"
610 PRINT
620 PRINT " SET TRANSDUCER VALVES IN POSITION TO GET ZERO DIFFERENTIAL PRESSURE"
630 T1=T/N3 TIME INTERVAL BETWEEN SAMPLES
640 DIM D'(3*N3)
650 FOR N1=1 TO N3
660   READ N2
670   D'(N1*3-2)=1 D'(N1*3-1)=N2 D'(N1*3)=0
680   IF N2=4 RESTORE
690 NEXT
700 PRINT
710 PRINT " PUSH EVENT SWITCH WHEN READY TO TAKE DATA FOR ZERO CONDITION"
720 X=AIN(1,4,0,1)
730 IF X>1 PNT 7 GOTO 760
740 GOTO 720
750
760 Z1=0 Z2=0
770 PRINT
780 PRINT " ZERO DATA IS BEING COLLECTED"
790 FOR N=1 TO 1000
800   Z1=AIN(1,1,0,1)+Z1
810 NEXT N
820
830
840 Z1=Z1/1000 Z2=0
850 PRINT
860 PRINT " ZERO DATA TAKEN"
870 PRINT
880 PRINT
890 INPUT "DO YOU WANT TO CHECK CALIBRATION "O$
900 X=ASC(O$)
910 IF X=89 GOTO 940
920 IF X=78 GOTO 1330
930 GOTO 890
940 PRINT "SET VALVES IN POSITION TO CALIBRATE D/P TRANSDUCER"
950 PRINT
960 WAIT 3
970 PRINT " SET CALIBRATION DIFFERENTIAL"
980 PRINT
990 WAIT 3
1000 PRINT " PUSH EVENT SWITCH WHEN CONDITIONS ARE READY TO TAKE CALIBRATION DATA"
```

```
1010
1020
1030 X=AIN(1,4,0,1)
1040 IF X>1 PNT 7 GOTO 1070
1050 GOTO 1030
1060
1070 C1=0 C2=0 C3=0
1080 PRINT "CALIBRATION DATA IS BEING COLLECTED"
1090 FOR N=1 TO 1000
1100   C1=AIN(1,1,0,1)+C1
1110   C2=AIN(1,2,0,1)+C2
1120   C3=AIN(1,3,0,1)+C3
1130 NEXT N
1140
1150
1160 C1=C1/1000 C2=C2/1000 C3=C3/1000
1170
1180 INPUT " MANOMETER READING IN PSI FOR THIS RUN = "P2
1190 PRINT "-----------------------"
1200 P1=(C1-Z1)*F
1210 P3=(P1-P2)/P2
1220 IF ABS(P3)<.005 GOTO 1300
1230 PRINT "MANOMETER CALIBRATION DOES NOT AGREE WITH TRANSDUCER SCALE FACTOR"
1240 PRINT "P1=";P1;"    ";"P2=";P2;"    ";"ERROR=";P3
1250 INPUT " DO YOU WANT TO CONTINUE USING THIS MANOMETER CALIBRATION (YES OR NO)"O$
1260 X=ASC(O$)
1270 IF X=78 GOTO 940
1280 IF X=89 GOTO 1300
1290 GOTO 1250
1300 P5=P2/(C1-Z1)
1310 PRINT " CALIBRATION DATA COMPLETE"
1320 GOTO 1340
1330 P5=F
1340 PRINT
1350 PRINT " SET VALVES IN TEST POSITION"
1360 PRINT
1370 PRINT " TAKE FLOW TO STEADY STATE CONDITION"
1380 PRINT " PUSH EVENT SWITCH WHEN FLOW IS STABLE"
1390
1400
1410 X=AIN(1,4,0,1)
1420 IF X>1 PNT 7 GOTO 1460
1430 GOTO 1410
1440
1450
1460 Z0=0 Z4=0 Z6=0
1470 PRINT
1480 PRINT "STEADY STATE DATA IS BEING COLLECTED"
1490 FOR X=1 TO 1000
1500   Z0=AIN(1,1,0,1)+Z0
```

```
1510   Z4=AIN(1,2,0,1)+Z4
1520   Z6=AIN(1,3,0,1)+Z6
1530 NEXT
1540 Z0=Z0/1000
1550 Z4=(Z4*E)*.001
1560 Z0=(Z0-Z1)*P5
1570 B5=ABS((Z6/1000)-Z3)*J1
1580 PRINT
1590 PRINT " STEADY STATE DATA TAKEN"
1600 PRINT
1610 PRINT
1620 ON ERROR 122,1630
1630 INPUT "UPPER POOL = "B2
1640 ON ERROR 122,1650
1650 INPUT "LOWER POOL = "B3
1660 PRINT
1670 PRINT " COMPUTER IS READY TO TAKE TEST DATA FOR TEST # ";N9
1680 PRINT
1690 PRINT " PUSH EVENT SWITCH WHEN GATES START TO CLOSE"
1700
1710 X=AIN(1,4,0,1)
1720 IF X>1 PNT 7 GOTO 1740
1730 GOTO 1710
1740 SCAN (D'(1),N3,T1) INTO Z(1)
1750 GTIME H,M1,S GDATE M,D1,Y2
1760 PRINT "TEST DATA FOR TEST # ";N9;"IS COMPLETE"
1770
1780 ON ERROR 111,1880
1790 Y1=20 Y=20 Z=0 DIM D'(2)
1800 FIND THE NUMBER OF SAMPLES IN RUN
1810 FOR X=1 TO N3
1820   READ N2
1830   IF N2=4 Y=Z(X)
1840   IF Y>Y1+1 EXIT FOR GOTO 1950
1850   Y1=Y
1860   IF N2=4 RESTORE
1870 NEXT
1880 X=X-1
1890 PRINT "MEMORY OVERFLOWED BEFORE END OF TEST"
1900 PRINT INPUT "DO YOU WANT TO CONTINUE (YES OR NO) "O$
1910 Y=ASC(O$)
1920 IF Y=89 GOTO 1950
1930 IF Y=78 RESTORE GOTO 3630
1940 GOTO 1890
1950 RESTORE
1960 DATA IS CONVERTED INTO ENGINEERING UNITS
1970 FOR Q=1 TO N3
1980   READ N2
1990   IF N2=1 Z(Q)=(Z(Q)-Z1)*P5
2000   IF N2=2 Z(Q)=(Z(Q)-Z2)*E
```

```
2010   IF N2=3 Z(Q)=(ABS(Z(Q)-Z3))*J1
2020   IF N2=4 RESTORE
2030 NEXT Q
2040
2050 FIRST ITERATION
2060 Y=X
2070 GOTO 2130
2080 INPUT "DO YOU WANT TO CONTINUE REDUCING DATA "O$
2090 X=ASC(O^)
2100 IF X=89 GOTO 2130
2110 IF X=78 GOTO 2530
2120 GOTO 2080
2130 A1=0 T2=T1*2
2140 FOR X=1 TO Y
2150   READ N2
2160   IF N2=1 A1=((Z(X)-((Z0*(Y-X))/Y))*T2)+A1
2170   IF N2=4 RESTORE
2180 NEXT
2190 N=0 D(1)=A1
2200 B(1)= D(1)
2210 Q(1)=(B(1)*A*144)/(R0*L)
2220 F(1)=ABS((Z0*D9*148.432*A2)/(L*(Q(1)↑2)))
2230 V(1)=Q(1)/A
2240 GOSUB 3760
2250 THIS ROUTINE COMPUTES AREA UNTIL CHANGE IS LESS THAN 0.1%
2260 X2=0
2270 DIM P6(N3)
2280 FOR N=1 TO 20
2290   T2=T1*2 X2=X2+1 X1=1
2300   FOR X=1 TO Y
2310     READ N2
2320     IF N2=1 P6(X1)=Z0*(((D(N)-D(N+1))/D(N))↑2)
2330     IF N2=1 D(N+1)=((Z(X)-P6(X1))*T2)+D(N+1) IF X2>2 IF V=5 AOT(2,1)=D(N+1)/V2-2 AOT(2,0)=(X*T1)/V1
2340     IF N2=4 RESTORE
2350     GOTO 2390
2360     PRINT "Z0=";Z0;TAB(20);"Z(X)=";Z(X);TAB(40);"P6(X1)=";P6(X1)
2370     PRINT "D(N)=";D(N);TAB(20);"D(N+1)=";D(N+1)
2380     PRINT PRINT PRINT
2390     IF N2=1 X1=X1+1
2400   NEXT X
2410   B(N)=D(N+1)
2420   Q(N)=(B(N)*A*144)/(R0*L)
2430   F(N) = ABS((Z0*D9*148.432*A2)/(L*(Q(N)↑2)))
2440   148.432=2*32.17*2.307
2450   V(N)=Q(N)/A
2460   GOSUB 4020
2470   IF X2>2 IF ABS((D(N)-D(N-1))/D(N))<.001 EXIT FOR GOTO 2490
2480 NEXT N
2490 PNT 12
2500 RESTORE
```

```
2510
2520
2530 INPUT "DO YOU WANT TO SAVE THE DATA  (YES OR NO)  "O$
2540 X=ASC(O$)
2550 IF X=78 GOTO 2800
2560 IF X=89 GOTO 2580
2570 GOTO 2530
2580 ON ERROR 17,2640
2590 PRINT "CHECK TAPE DRIVE"
2600 PRINT "I YOU HAVE A MACBASIC ERROR RUN 2580"
2610 INPUT " INPUT FILE NAME FOR DATA " S$
2620 INPUT " INPUT FILE NAME FOR VARIABLES " T1$
2630 GOTO 2650
2640 PRINT "ILLEGAL FILE NAME" GOTO 2610
2650 T(1)=T1 T(2)=T T(3)=H T(4)=M1
2660 T(5)=S T(6)=M T(7)=D1 T(8)=Y2
2670 T(9)=B T(10)=D9 T(11)=L T(12)=F2
2680 T(13)=R0 T(14)=F T(15)=E T(16)=Z3
2690 T(17)=J1 T(18)=B2 T(19)=B3 T(20)=B5
2700 T(21)=N9 T(22)=A T(23)=N3 T(24)=Z0
2710 T(25)=P5 T(26)=A2 T(27)=A3 T(28)=Y
2720 SAVE ARRAY Z(1) S$
2730 SAVE ARRAY T(1) T1$
2740 INPUT "DO YOU WANT TO PLOT THE DATA "O$
2750 GOSUB 4040
2760 X=ASC(O$)
2770 IF X=89 GOTO 4530
2780 IF X=78 GOTO 2800
2790 GOTO 2740
2800 INPUT " DO YOU WANT A TABULATION OF DATA (YES OR NO) "O$
2810 X=ASC(O$)
2820 IF X=78 RESTORE GOTO 3620
2830 IF X=89 GOTO 2850 YES
2840 GOTO 2800
2850 PRINT " YOU HAVE ";Y/6; "LINES OF DATA"
2860 ON ERROR 122,2870
2870 INPUT "HOW MANY DO YOU WANT TO TABULATE  "W
2880 PNT 12
2890 DIM G1$(10),G2$(10),G3$(10)
2900 DIM C$(35),E$(10),V$(10)
2910 DIM T$(10),M$(20)
2920 G1$="D/P #1"
2930 G2$="D/P #2"
2940 G3$="D/P #3"
2950 E$="ABSOLUTE"
2960 V$="BASELINE"
2970 C$="GATE OPENING(%)"
2980 M$="STROKE(IN.)"
2990 T$="TIME (SEC)"
3000 W2=55
```

```
3010 PRINT TAB(W2);"PRESSURE MOMENTUM TEST"
3020 PRINT TAB(W2);"PROJECT ";A$
3030 PRINT TAB(W2);"TURBINE # : ";B
3040 PRINT TAB(W2);"TEST # : ";N9
3050 PRINT TAB(W2);"DATE : ";M;"/";D1;"/";Y2
3060 PRINT TAB(W2);"TIME : ";H;":";M1;":";S
3070 FOR X=1 TO 5
3080   PRINT
3090 NEXT
3100 FOR X=1 TO 6
3110   READ N2
3120 NEXT
3130 DATA 1,6,2,3,4,5,7,8
3140 FOR X=1 TO 8
3150   READ N2
3160   Q1=((X-1)*15)+9
3170   IF N2=1 PRINT TAB(Q1);T$;
3180   IF N2=2 PRINT TAB(Q1);M$;
3190   IF N2=3 PRINT TAB(Q1);G1$;
3200   IF N2=4 PRINT TAB(Q1);G2$;
3210   IF N2=5 PRINT TAB(Q1);G3$;
3220   IF N2=6 PRINT TAB(Q1-3);C$;
3230   IF N2=7 PRINT TAB(Q1);E$;
3240   IF N2=8 PRINT TAB(Q1);V$;
3250 NEXT
3260 RESTORE
3270 PRINT
3280 FOR X=1 TO 132
3290   PRINT "-";
3300 NEXT
3310 PRINT
3320 DATA IS TABULATED
3330 RESTORE
3340 GOSUB 3710
3350 X1=1 W=INT((Y/6)/W)*6
3360 Q2=1 Q3=0
3370 FOR X=Q2 TO (Y-W) STEP W
3380   FOR Q=1 TO 8
3390     READ N2
3400     Q1=((Q-1)*15)+9
3410     IF N2=1 PRINT TAB(Q1);T1*(X-1);
3420     IF N2=2 PRINT TAB(Q1);Z(X+3)*0.16938;
3430     IF N2=3 PRINT TAB(Q1);Z(X);
3440     IF N2=4 PRINT TAB(Q1);Z(X+2);
3450     IF N2=5 PRINT TAB(Q1);Z(X+4);
3460     IF N2=6 PRINT TAB(Q1);Z(X+3);
3470     IF N2=7 PRINT TAB(Q1);Z(X+1);
3480     IF N2=8 PRINT TAB(Q1);ABS(P6(X1));
3490   NEXT Q
3500   X1=X1+(W/2)
```

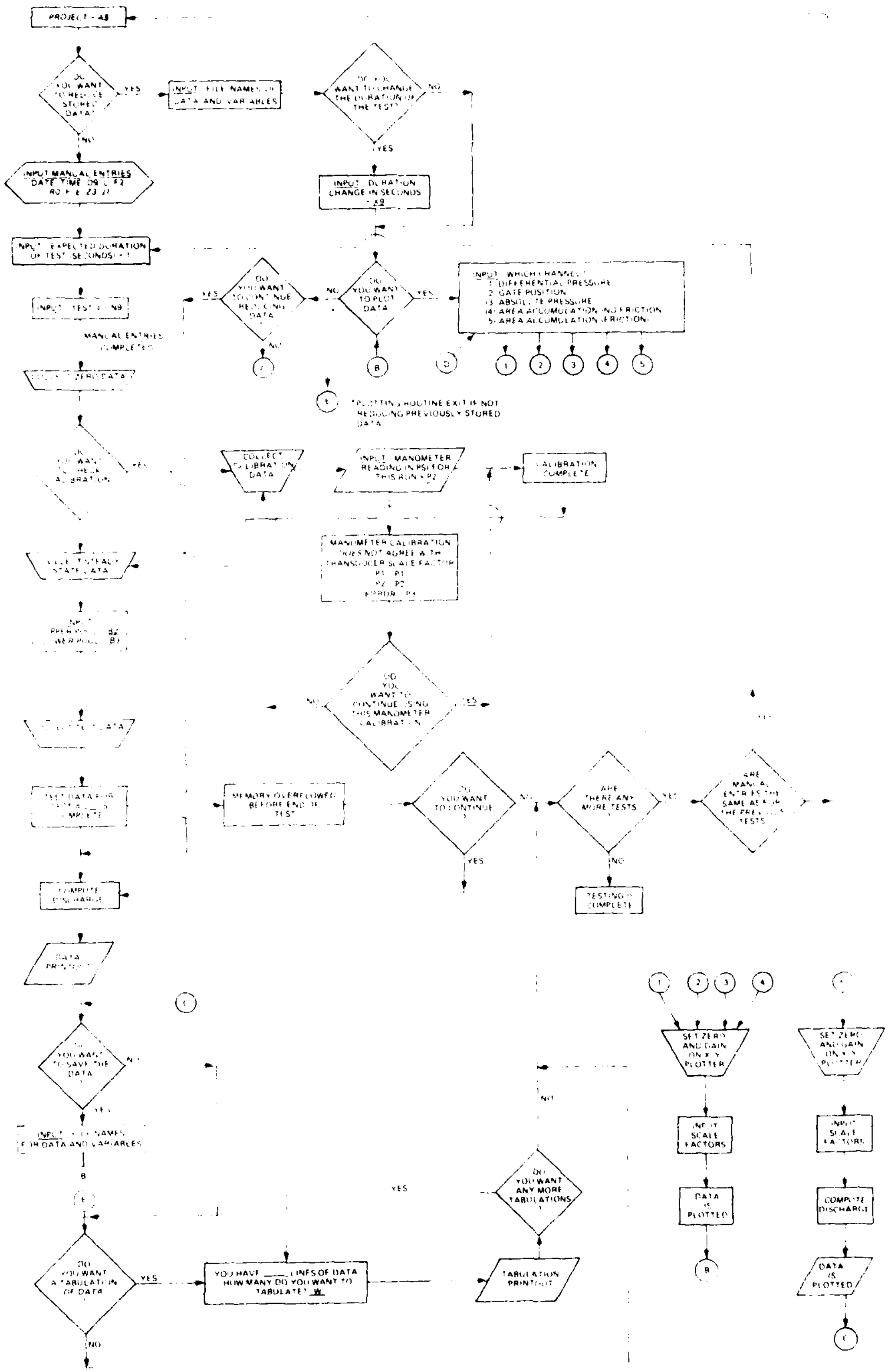
```
3510   RESTORE
3520   PRINT
3530   GOSUB 3710
3540 NEXT X
3550 IF Q3=0 Q2=Y-5 W=6 Q3=1 GOTO 3370
3560 PNT 12
3570 INPUT " DO YOU WANT ANY MORE TABULATIONS  (YES OR NO) "O$
3580 X=ASC(O$)
3590 IF X=89 RESTORE GOTO 2850
3600 IF X=78 RESTORE GOTO 3620
3610 GOTO 3570
3620
3630 INPUT " ARE THERE ANY MORE TESTS  (YES OR NO) "O$
3640 GOSUB 4040
3650 X=ASC(O$)
3660 IF X=89 GOTO 180
3670 IF X=78 GOTO 3690
3680 GOTO 3630
3690 PRINT " TESTING IS COMPLETE"
3700 END
3710 FOR U=1 TO 6
3720   READ N2
3730 NEXT
3740 RETURN
3750
3760 PNT 12
3770 W=44
3780 PNT 14
3790 PRINT TAB(33-(LEN(A$)+10)/2);"PROJECT : ";A$
3800 PNT 15
3810 PRINT TAB(W);"TEST # :";N9
3820 PRINT TAB(W);"DATE : ";M;"/";D1;"/";Y2 TAB(W);"TIME : ";H;":";M1;":";S
3830 PRINT TAB(W);"TURBINE # : ";B TAB(W);"PENSTOCK DIAMETER : ";D9
3840 PRINT TAB(W);"UPPER POOL : ";B2 TAB(W);"LOWER POOL : ";B3
3850 PRINT TAB(W);"% GATE OPENING : ";B5
3860 PRINT TAB(W);"CLOSURE TIME : ";(Y*T1) TAB(W);"TIME INCREMENT : ";T1
3870 PRINT TAB(W);"DISTANCE BETWEEN PIEZOMETER RINGS IN FT. : ";L
3880 PRINT TAB(W);"STEADY-STATE FRICTION LOSS AT START OF TEST : ";Z0
3890 PRINT PRINT PRINT PRINT
3900 FOR G=1 TO 132
3910   PRINT "-";
3920 NEXT
3930 PRINT
3940 W=20
3950 PRINT TAB(W);"ITERATION";TAB(W*2);"INTEGRAL";TAB(W*3);"DISCHARGE";TAB(W*4);"VELOCITY";TAB(W*5);"FRICTION"
3960 PRINT TAB(W+3);"(#)";TAB(W*2);"(PSI-SEC)";TAB(W*3+2);"(CFS)";TAB(W*4+2);"(FPS)"
3970 FOR G=1 TO 132
3980   PRINT "-";
3990 NEXT
4000 PRINT
```

```
4010 IF N=0 PRINT TAB(W+4);N;TAB(W*2);B(1);TAB(W*3);Q(1);TAB(W*4);V(1);TAB(W*5);F(1)
4020 IF N>=1 PRINT TAB(W+4);N;TAB(W*2);B(N);TAB(W*3);Q(N);TAB(W*4);V(N);TAB(W*5);F(N)
4030 RETURN
4040 FOR O=1 TO 21
4050   D(O)=0
4060 NEXT
4070 RETURN
4080 END
4090 Y=0
4100 FOR X=1 TO 10
4110   Y=AIN(1,1,0,1)+Y
4120 NEXT
4130 Y=Y/10
4140 PRINT "DIFFERENTIAL PRESSURE CELL = ";Y
4150 WAIT 1
4160 GOTO 4090
4170 ON ERROR 17,4180
4180 INPUT " FILE NAME FOR DATA " S$
4190 INPUT " FILE NAME FOR VARIABLES " T1$
4200 LOAD ARRAY Z(1) S$
4210 LOAD ARRAY T(1) T1$
4220 T1=T(1) T=T(2) H=T(3) M1=T(4)
4230 S=T(5) M=T(6) D1=T(7) Y2=T(8)
4240 B=T(9) D9=T(10) L=T(11) F2=T(12)
4250 R0=T(13) F=T(14) E=T(15) Z3=T(16)
4260 J1=T(17) B2=T(18) B3=T(19) B5= T(20)
4270 N9=T(21) A=T(22) N3=T(23) Z0=T(24)
4280 P5=T(25) A2=T(26) A3=T(27) Y=T(28)
4290 INPUT " DO YOU WANT TO CHANGE THE DURATION OF THE TEST  " O$
4300 X=ASC(O$)
4310 IF X=89 GOTO 4340
4320 IF X=78 GOTO 4400
4330 GOTO 4290
4340 PRINT "THE EXPECTED DURATION OF THIS TEST = ";T; "SECONDS"
4350 PRINT
4360 INPUT "DURATION CHANGE IN SEC. = "X9
4370 IF X9>=0 Y=INT((X9/T1)/6)*6+Y
4380 IF X9<0 Y=(INT((X9/T1)/6)-1)*6+Y
4390 IF Y>N3 Y=N3
4400 INPUT "DO YOU WANT TO PLOT DATA "O$
4410 X=ASC(O$)
4420 IF X=89 GOTO 4530
4430 IF X=78 IF E9=1.0 GOTO 2080
4440 IF X=78 IF E9=2.0 GOTO 2800
4450 GOTO 4400
4460 FOR O=6 TO 3600 STEP 6
4470   PRINT P6(O)
4480 NEXT
4490 FOR T9=6 TO 3606 STEP 6
4500   PRINT Z(T9);
```

```
4510 NEXT
4520 END
4530 PRINT "WHICH CHANNEL (1,2,3,4,5)"
4540 PRINT "(1) = DIFFERENTIAL PRESSURE"
4550 PRINT "(2) = GATE POSITION"
4560 PRINT "(3) = ABSOLUTE PRESSURE"
4570 PRINT "(4) = AREA ACCUMULATION(NO FRICTION)"
4580 PRINT "(5) = AREA ACCUMULATION(FRICTION CALCULATED)"
4590 INPUT "CHANNEL = "V
4600 IF V<=3 U=0 W5=0 GOTO 4620
4610 IF V>3 U=0 W5=-2 GOTO 4620
4620 AOT(2,0)=U AOT(2,1)=W5
4630 INPUT "SET ZERO ON X-Y PLOTTER AND TYPE (CR)"O$
4640 AOT(2,0)=9 AOT(2,1)=3
4650 PRINT "SET GAIN ON X-AXIS FOR 9"
4660 PRINT "SET GAIN ON Y-AXIS FOR 3"
4670 INPUT "TYPE (CR)"O$
4680 AOT(2,0)=U AOT(2,1)=W5
4690 INPUT "SCALE FACTOR FOR X-AXIS = "V1
4700 INPUT "SCALE FACTOR FOR Y-AXIS = "V2
4710 INPUT "SET PEN IN DOWN POSITION AND TYPE (CR)"O$
4720 IF V=4 GOTO 4830
4730 IF V=5 GOTO 2130
4740 FOR X=1 TO Y
4750   READ N2
4760   IF N2=1 IF V=1 AOT(2,1)=Z(X)/V2
4770   IF N2=2 IF V=3 AOT(2,1)=Z(X)/V2-10
4780   IF N2=3 IF V=2 AOT(2,1)=Z(X)/V2
4790   AOT(2,0)=(X*T1)/V1
4800   IF N2=4 RESTORE
4810 NEXT
4820 GOTO 4400
4830 A1=0 T2=T1*2
4840 FOR X=1 TO Y
4850   READ N2
4860   IF N2=1 IF V=4 A1=(Z(X)*T2)+A1 AOT(2,1)=A1/V2-2
4870   AOT(2,0)=(X*T1)/V1
4880   IF N2=4 RESTORE
4890 NEXT
4900 PRINT PRINT PRINT
4910 PRINT "ACCUMULATED AREA(NO FRICTION) = ";A1
4920 GOTO 4400
8000 Q=0
8010 PRINT "WHICH CHANNEL (1,2,3) "
8030 PRINT "(2)= ABSOLUTE PRESSURE CELL"
8040 PRINT "(3)= GATE POSITION OR ZERO GATE CLOSURE"
8050 INPUT "CHANNEL = "V9
8060 FOR I=1 TO 5
8070   Y=0
8080   FOR N=1 TO 1000
```

```
8090     Y=AIN(1,V9,0,1)+Y
8100   NEXT N
8110   Y=Y/1000
8120   PRINT "VOLTAGE = ";Y
8130   Q=Y+Q
8140   WAIT 2
8150 NEXT I
8160 A=Q/5
8170 PRINT "AVERAGE VOLTAGE = ";A
8180 END
```

C2. Program Flowchart

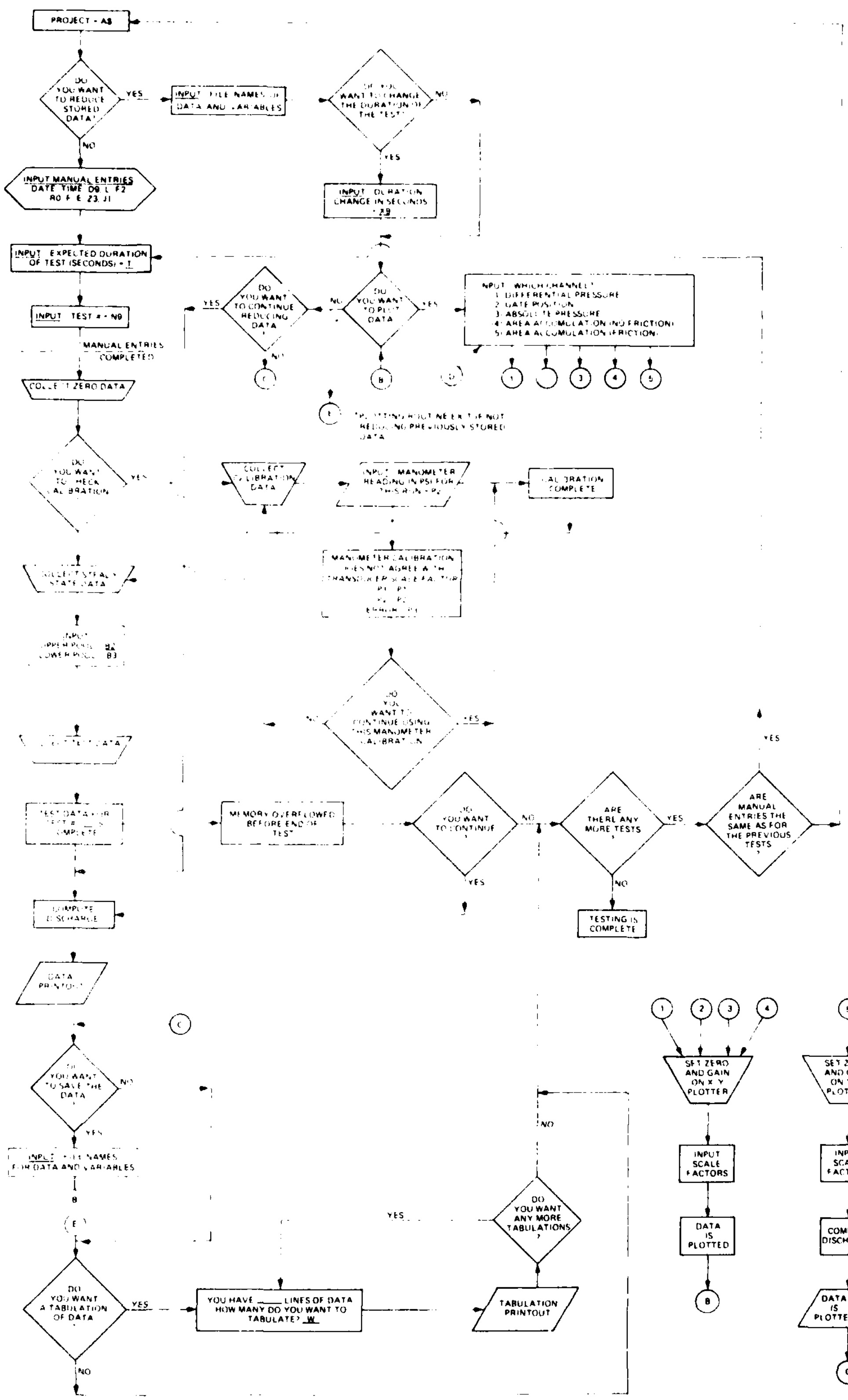


C3. Variable Listing

(Alphabetical order)

A	Penstock Area
A1	Initial Area-Under-Curve (iteration Ø)
A2	(Penstock Area)^2
A3	(Penstock Area)^2 * 144
A$	Project Name
B	Turbine Number
B2	Upper Pool Elevation
B3	Lower Pool Elevation
B5	Initial Gate Position (volts)
B$	(Dimensioned but not used)
B(N)	Area-Under-Curve (same as D(N))
C1	Calibration Data (differential)
C2	Calibration Data (absolute)
C3	Calibration Data (gate opening)
C$	"GATE OPENING (%)"
D1	Day (date)
D9	Penstock Diameter
D(N)	Area-Under-Curve (same as B(N))
E	Absolute Pressure Calibration Factor
E9	1.0 = Stored Data Reduction
	2.0 = Run Test
E$	"ABSOLUTE"
F	Differential Pressure Calibration Factor
F2	Water Temperature (°F)
F(N)	Friction Factor
G	Loop Variable for Repetitive Printing
G1$	"D/P #1"
G2$	"D/P #2"
G3$	"D/P #3"
H	Hours (time)
J1	Gate Position Calibration Factor
L	Penstock Test Length
M	Month (date)

C2. Program Flowchart



C3. Variable Listing

(Alphabetical order)

A	Penstock Area
A1	Initial Area-Under-Curve (iteration Ø)
A2	$(\text{Penstock Area})^2$
A3	$(\text{Penstock Area})^2 * 144$
A$	Project Name
B	Turbine Number
B2	Upper Pool Elevation
B3	Lower Pool Elevation
B5	Initial Gate Position (volts)
B$	(Dimensioned but not used)
B(N)	Area-Under-Curve (same as D(N))
C1	Calibration Data (differential)
C2	Calibration Data (absolute)
C3	Calibration Data (gate opening)
C$	"GATE OPENING (%)"
D1	Day (date)
D9	Penstock Diameter
D(N)	Area-Under-Curve (same as B(N))
E	Absolute Pressure Calibration Factor
E9	1.0 = Stored Data Reduction
	2.0 = Run Test
E$	"ABSOLUTE"
F	Differential Pressure Calibration Factor
F2	Water Temperature (°F)
F(N)	Friction Factor
G	Loop Variable for Repetitive Printing
G1$	"D/P #1"
G2$	"D/P #2"
G3$	"D/P #3"
H	Hours (time)
J1	Gate Position Calibration Factor
L	Penstock Test Length
M	Month (date)

M1	Minutes (time)
M$	"STROKE (IN.)"
N	Iteration Number (internal)
N1	Used in Loop to Set Up Memory
N2	Data Channel (1, 2, 3, or 4)
N3	Number of Samples (total all channels)
N9	Test Number
O$	String for Decision Inputs (Yes or No)
P1	Differential Pressure - transducer (calibration check)
P2	Manometer Reading (PSI)
P3	Error = (P1-P2)/P2
P5	Differential Pressure Calibration Factor (P5=F)
P6(X1)	Baseline
Q	Loop Variable
Q1	Word Spacing (print out)
Q2	Tabulation Spacing
Q3	Tabulation Spacing
Q(N)	Discharge (CFS)
RØ	Water Density (slugs/cu ft)
S	Seconds (time)
S$	File Name for Data
T	Expected Test Duration
T1	Time Interval Between Samples
T2	Time Interval Between D/P Data Samples
T9	Event Switch Voltage Location
T$	"TIME (SEC)"
T1$	File Name for Variables
U	Pen Location (starting point) - X-Axis
V	Plot Channel
V1	Scale Factor for X-Axis
V2	Scale Factor for Y-Axis
V9	Preliminary Calibration Channel Number
V$	"BASELINE"
V(N)	Velocity (FPS)
W	Number of Lines to Tabulate
W2	Word Spacing

W5	Pen Location (starting point) - Y-Axis
X	Data Point
X1	Sample Number
X2	Iteration Number
Y	Number of Samples in Run (computing)
Y1	Number of Samples in Run
Y2	Year (date)
Z∅	Steady State Data (differential)
Z1	Zero Data (differential)
Z2	Zero Data (absolute)
Z3	Zero Gate Position Voltage
Z4	Steady State Data (absolute)
Z6	Steady State Data (initial gate opening)
Z(Q)	Variable for Converting Z(X) into Engineering Units
Z(X)	Data Memory Location

Total No. of Variables = 83

APPENDIX D

CHARTS AND GRAPHS

PLATE D1

PRESSURE-MOMENTUM TURBINE EFFICIENCY TEST
PRELIMINARY CALIBRATION WORKSHEET

Project: Fort Randall - Unit 2 **Date:** 9 August 1983 **Operator:** ______

DIFFERENTIAL PRESSURE TRANSDUCER				GATE OPENING SENSOR				ABSOLUTE PRESSURE TRANSDUCER			
(1) ZERO PRESSURE VOLTAGE 1.692				(1) ZERO GATE VOLTAGE 0.670				(1) ZERO PRESSURE VOLTAGE 0			
(2) ΔP (PSID)	(3) Voltage	(4) ΔV (3)-(1)	Factor (2)/(4)	(2) G.O.(%)	(3) Voltage	(4) ΔV (3)-(1)	Factor (2)/(4)	(2) P(PSI)	(3) Voltage	(4) ΔV (3)-(1)	Factor (2)/(4)
Positive											
5.120	2.972	1.280	4.00	0	0.670						
3.919	2.670	0.978	4.01	100	8.682	8.012	12.481	Calibrated with deadweight tester.			
3.217	2.491	0.799	4.03	80	7.105	6.435	12.432				
2.583	2.337	0.645	4.00	60	5.551	4.881	12.293			Factor =	100.0
1.858	2.152	0.460	4.04	40	3.937	3.267	12.244				
0.906	1.918	0.226	4.01								
0.0	1.692	0				Σ =	49.45				
						Avg	12.36				
Negative											
3.126	0.910	0.782	4.00								
2.515	1.064	0.628	4.00								
1.767	1.246	0.446	3.96								
0.884	1.467	0.225	3.93								
		Σ =	39.98								
		Avg	4.00								

PRESSURE-MOMENTUM DISCHARGE MEASUREMENT DATA SHEET

PROJECT ______________ DATE ______________

TEST NO.	TIME START	GATE OPENING %	WATER TEMP °F	UPPER POOL ELEV	LOWER POOL ELEV	MW READING	EXPECTED CLOSURE TIME SEC	Q CFS	ABSOLUTE PRESSURE PSI	DATA STORAGE		COMMENTS
										DATA	VARIABLES	

PLATE D2

PROJECT : FORT RANDALL UNIT 2

TEST # :6
DATE : 8 /9 /80
TIME : 14 :28 :37
TURBINE # : 2
PENSTOCK DIAMETER : 22
UPPER POOL : 1354.81
LOWER POOL : 1234.59
% GATE OPENING : 40.4473
CLOSURE TIME : 40
TIME INCREMENT : .0111111
DISTANCE BETWEEN PIEZOMETER RINGS IN FT. : 80
STEADY-STATE FRICTION LOSS AT START OF TEST : -.025898

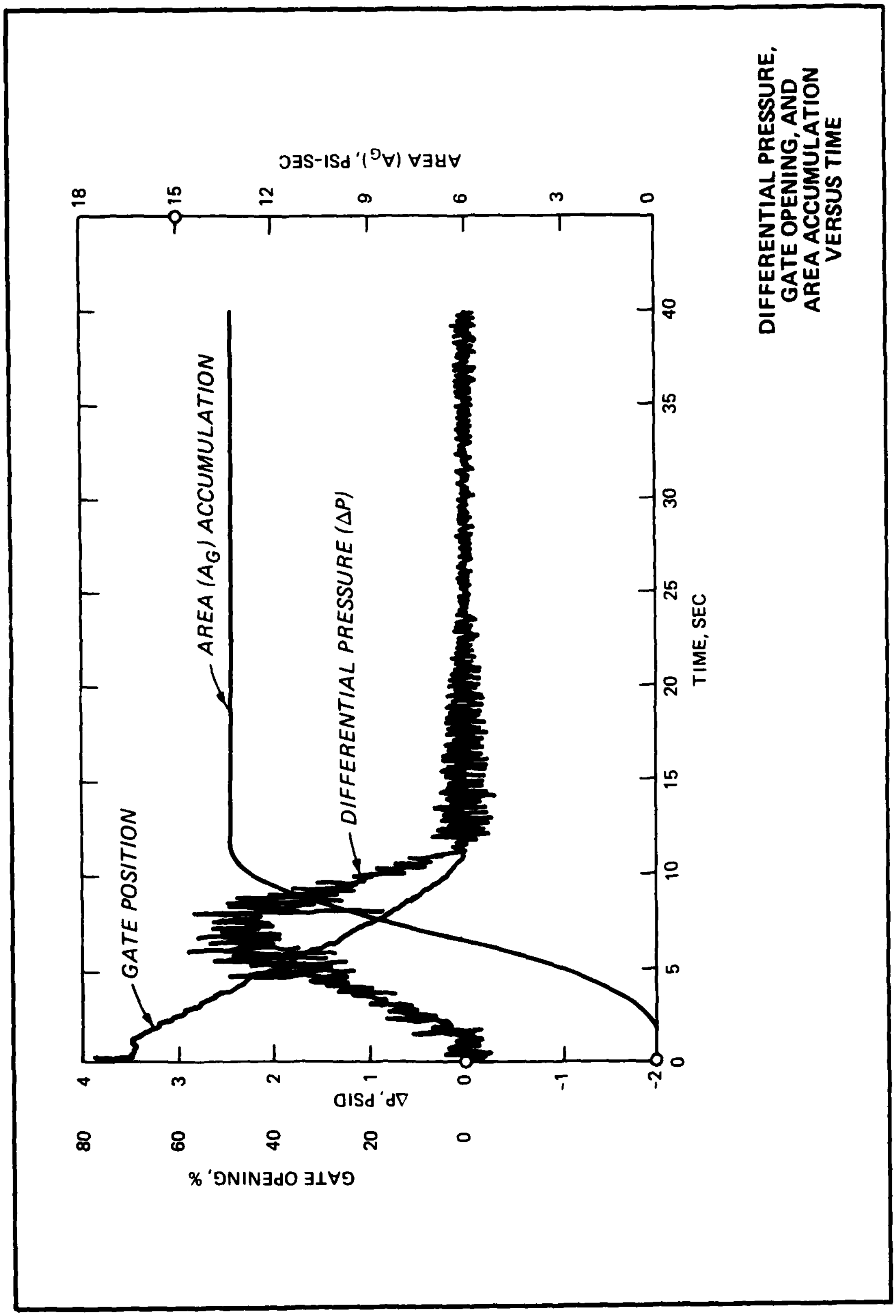
ITERATION (#)	INTEGRAL (PSI-SEC)	DISCHARGE (CFS)	VELOCITY (FPS)	FRICTION
0	9.15878	3236.98	8.51539	.0145786
1	8.7261	3084.05	8.11311	.0160602
2	8.72144	3082.41	8.10878	.0160774
3	8.7214	3082.4	8.10874	.0160775

PLATE D3

PRESSURE MOMENTUM TEST
PROJECT FORT RANDALL UNIT 2
TURBINE # : 2
TEST # : 6
DATE : 8 /9 /83
TIME : 14 :28 :37

TIME (SEC)	GATE OPENING(%)	STROKE(IN.)	D/P #1	D/P #2	D/P #3	ABSOLUTE	BASELINE
0	40.5432	6.86721	1.78502	2.27799	2.53189	46.3867	.025898
1	39.2758	6.65254	-.51498	-.82748	-1.06186	47.3633	.024442
2	32.4561	5.49741	.500645	.0709572	.168613	62.5	.0208547
3	22.6188	3.33117	1.12564	.969395	.676426	74.2188	.0133511
4	15.9175	2.69649	1.28189	1.61393	2.1608	76.6602	6.18326E-3
5	9.52251	1.61292	2.04361	1.73111	1.47721	69.3359	1.78771E-3
6	3.84946	.652022	1.12564	1.32096	1.36002	62.0117	2.92879E-4
7	.892238	.151127	.695957	.383457	.188145	52.2461	1.74205E-5
8	.0473162	8.01441E-3	-.241543	-.222012	-.1048241	46.875	3.9022E-6
9	.0473162	8.01441E-3	.168613	.246738	.11002	51.2695	3.79237E-6
10	.0130354	2.20794E-3	-.124355	-.241543	-.0657616	45.8984	2.60841E-6
11	.0473162	8.01441E-3	.0904884	.0709572	.129551	48.3398	3.36854E-6
12	.616551	.1044314	-.0462303	-.0657616	-.0852928	50.7813	2.71335E-6
13	.0130354	2.20794E-3	.207676	.0904884	.149082	45.4102	2.77996E-6
14	.409425	.0693435	-.124355	.0318947	.0123634	49.3164	2.95655E-6
15	.288722	.0489038	.129551	.0514259	.0709572	47.8516	3.16708E-6
16	.375145	.063542	-.0657616	-.0462303	-.143887	46.3867	2.87548E-6
17	.375145	.063542	.0904884	.188145	.0123634	50.7813	2.44519E-6
18	.375145	.063542	-7.16782E-3	-.0462303	-.0657616	47.8516	1.49679E-6
19	.314793	.0533197	.129551	.149082	.0123634	48.8281	1.46778E-6
20	.616551	.1044314	-.1048241	-.0852928	-.0852928	50.7813	1.09713E-6
21	.349074	.0591261	.0709572	.11002	.0318947	46.875	1.19154E-6
22	.0473162	8.01441E-3	-.0657616	-.124355	-7.16782E-3	49.3164	1.34501E-6
23	.0473162	8.01441E-3	.0904884	-.0462303	.0709572	48.8281	1.64852E-6
24	.254442	.0430973	-.1048241	-.0462303	-.163418	47.8516	1.0645E-6
25	.168019	.0284591	.0709572	-.0462303	-7.16782E-3	48.8281	1.4691E-6
26	.349074	.0591261	-.0266991	-.0657616	-.0462303	47.8516	7.46205E-7
27	.133739	.0226526	.0709572	.0904884	-7.16782E-3	48.8281	7.25735E-7
28	.0130354	2.20794E-3	-.0462303	.0318947	-7.16782E-3	48.8281	4.95387E-7
29	.254442	.0430973	.0318947	-7.16782E-3	.0904884	48.3398	2.41808E-7
30	.228371	.0386814	.0514259	.0514259	-7.16782E-3	47.8516	7.82077E-8
31	.530129	.0897931	-.0657616	-.0462303	.0514259	48.8281	5.94351E-8
32	.375145	.063542	.0514259	-7.16782E-3	-.124355	48.8281	9.24335E-8
33	.288722	.0489038	-.0852928	-7.16782E-3	.0318947	49.3164	7.18937E-8
34	.0473162	8.01441E-3	-7.16782E-3	-.0657616	-.0657616	48.3398	8.77957E-8
35	.254442	.0430973	-7.16782E-3	-7.16782E-3	-.0657616	48.8281	1.05251E-7
36	.073387	.0124303	-7.16782E-3	-7.16782E-3	.0514259	48.8281	1.02314E-7
37	.288722	.0489038	-7.16782E-3	.0318947	-7.16782E-3	47.3633	5.22368E-8
38	.073387	.0124303	.0123634	-.0266991	.0514259	47.8516	5.26405E-9
39.9333	.133739	.0226526	.0514259	.0514259	.0514259	48.3398	7.17039E-9

PLATE D4



DIFFERENTIAL PRESSURE, GATE OPENING, AND AREA ACCUMULATION VERSUS TIME
AREA (A_G), PSI-SEC
18
15
12
9
6
3
0
GATE POSITION
AREA (A_G) ACCUMULATION
DIFFERENTIAL PRESSURE (ΔP)
TIME, SEC
0
5
10
15
20
25
30
35
40
ΔP, PSID
4
3
2
1
0
-1
-2
GATE OPENING, %
80
60
40
20
0

PLATE D5

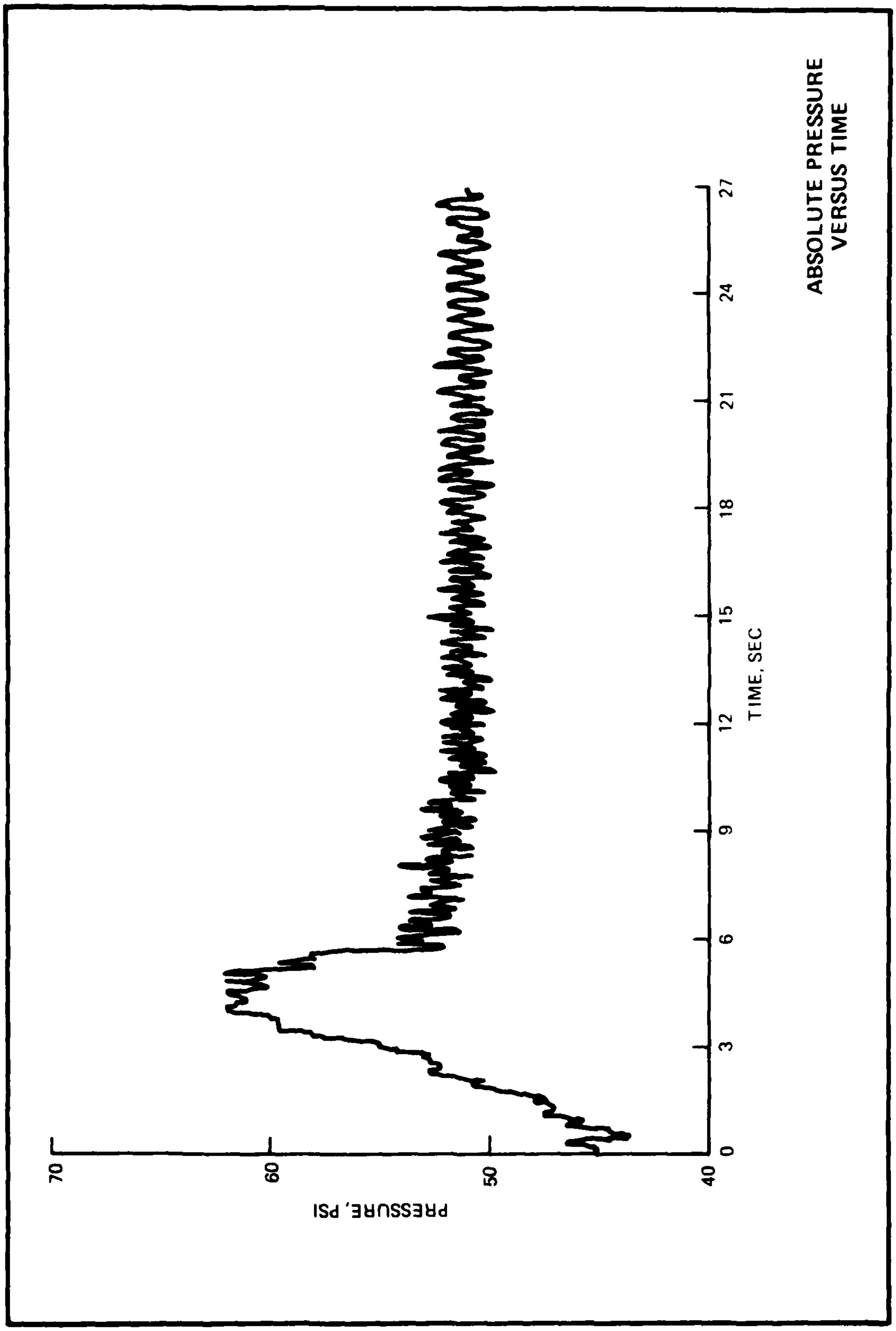

ABSOLUTE PRESSURE
VERSUS TIME
PRESSURE, PSI
TIME, SEC
70
60
50
40
0
3
6
9
12
15
18
21
24
27

PLATE D6

ATE

LMED